NATIONAL PETROLEUM RESERVE - ALASKA

Engineering Considerations for Gravel Alternates in NPR-A

Appendix 8 to the Draft Environmental Assessment

United States Department of the Interior
Bureau of Land Management

Alaska State Office
701 C Street Box 13
Anchorage, Alaska 99513

June 1981

IN REPLY REFER TO

A-2360 (914)

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
ALASKA STATE OFFICE
OFFICE OF SPECIAL PROJECTS
701 C Street, Box 30
Anchorage, Alaska 99513

MAY 27 1981

Memorandum

To: Program Manager, NPR-A (916)

From: Manager, OSP

Subject: Technical Report on Engineering Considerations for Gravel Alterations in NPR-A

In accordance with your request of February 19, 1981, the following are enclosed:

1. A "mock-up" of the report, including machine copies of figure photos.

2. Original text with machine copies of figure photos, with a set of Mag Cards.

3. One set of original figure photos.

If you need assistance to mount the photos as shown on the machine copy of figure pages, please let us know.

Mr. Yil Kuranel plans to review the report with members of your staff on Thursday, May 28, 1981.

Jim Richardson

Enclosures--3

ENGINEERING CONSIDERATIONS
FOR
GRAVEL ALTERNATES
IN
NPR-A

This Report Prepared by
Office of Special Projects
Alaska State Office, BLM
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June 1, 1981

GRAVEL CONSIDERATIONS
FOR
GRAVEL ALTERNATES
IN
NPR-A

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Abstract

This appendix describes alternates to gravel for construction of embankments in the North Slope of Alaska, particularly in NPR-A in a brief technical paper, prepared simultaneously with the EA.

In order to achieve full development of the natural resources of NPR-A, construction of extensive surface transportation facilities, drill pads, work pads, and similar structures must be considered a reality. Historically, in the NPR-A, surface facilities have primarily included temporary and experimental installation; however, these facilities are only the beginning of the development networks required to market the energy resources of the NPR-A. It is the intent of this paper to discuss current aspects of alternates for the above mentioned structures that are associated with the full development of this area. Broadly speaking, these alternates include: 1) Sands and silts with synthetic fabric and membranes insulating materials, and chemical binders; 2) Light weight aggregate (LWA products); 3) Mats (aluminum, plastic, fiberglass, and steel, and treated and fiberglass coated plywood); 4) Winter roads, (winter trails, snow roads, and ice roads); 5) Quarries, and; 6) Piles. The present experimental and exploratory embankment and similar structural designs and construction in NPR-A recognizes the perenially frozen subsoil characteristics, commonly referred to as permafrost. This paper includes a review and analysis of some of the gravel alternates for design and construction of structures over permafrost and active frost layers and the problems resulting from the thaw of the permafrost within the active layer of unstable soil materials as often observed on the Arctic regions in NPR-A.

Nature maintains permafrost in a delicate thermal equilibrium. Slight changes of any kind, whether they be thermal or physical, will upset this equilibrium and induce thaw. Design and construction of structures as mentioned above in the NPR-A must have full cognizance of the Arctic environmental conditions, problems, and their solutions. A knowledge of the principles of Arctic geomorphology and the process of heat transfer is essential so that proper design of the facilities will result in thermal harmony with this delicate Arctic environment. This paper presents, in general terms, the consideration for embankment design, construction and maintenance and focuses in detail on certain special topics and techniques resulting from the writer's and others experiences in these Arctic regions. It is not engineers design manual, but a presentation of available materials and techniques as considered from an engineering point of view that may be used and have been used in the NPR-A region of the Arctic.

ENGINEERING CONSIDERATIONS FOR GRAVEL ALTERNATES IN NPR-A

I. INTRODUCTION

The ever-increasing energy demands of the Western world and change of hands of the energy sources in the Middle East created an urgent need to market the vast energy reserves in North America, and particularly in the Arctic Regions of the State of Alaska. The National Petroleum Reserve of Alaska (NPR-A) is one of these Arctic regions which lies to the west of the Prudhoe Bay oil fields and south of Barrow (Fig. 1).

In order to achieve full development of the natural resources of NPR-A, construction of extensive surface transportation facilities, drill pads, work pads, and similar structures must be considered a reality. Historically in the NPR-A, surface facilities have primarily included temporary and experimental installations; however, these facilities are only the beginnings of the development networks required to market the energy resources of the NPR-A.

The intent of this paper is to discuss current aspects of gravel alternates for above mentioned structures that are associated with the full development of this area. The present experimental and exploratory embankment and similar structural designs and construction in NPR-A recognizes the perennially frozen subsoil characteristics, commonly referred to as permafrost. This paper also includes a review and analysis of some of the gravel aggregate alternates for design and construction of structures over permafrost and active frost layers, and the problems resulting from permafrost decay within the active layer of unstable soils often observed in the Arctic regions in NPR-A.

Nature maintains permafrost in a delicate thermal equilibrium. Slight changes of any kind, whether they are thermal or physical, upset this equilibrium and induce thaw. Design and construction of structures in the NPR-A must have full cognizance of the arctic environmental conditions, the problems, and their solutions. A knowledge of the principles of arctic geomorphology and the process of heat transfer is essential so that proper design of the facilities will result in thermal harmony with this delicate environment.

This paper is not an engineer's design manual, but it is an engineering presentation of gravel alternate materials and techniques that may be used and have been used in NPR-A.

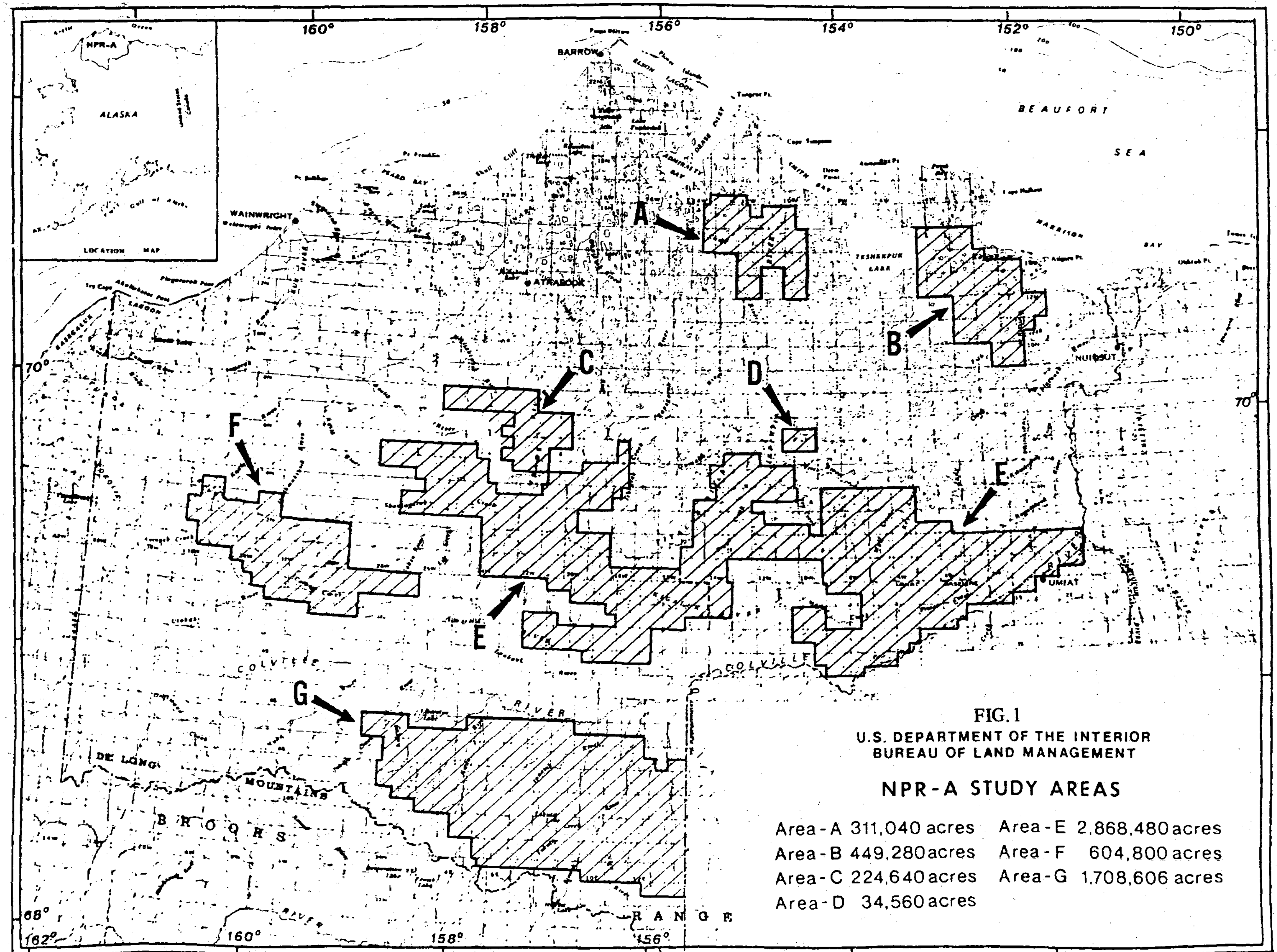


FIG. 1
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

NPR-A STUDY AREAS

Area - A 311,040 acres	Area - E 2,868,480 acres
Area - B 449,280 acres	Area - F 604,800 acres
Area - C 224,640 acres	Area - G 1,708,606 acres
Area - D 34,560 acres	

II. THE AREA

A. Physiographic and Geographical Data

The National Petroleum Reserve in Alaska covers approximately 37,000 square miles (96,000 square kilometers), Fig. 2. Three major features of the interior plains and the North American Cordillera as presented by the physiographic provinces and their subdivisions are listed below.

1. The Arctic Coastal Plain Province

The Arctic Coastal Plain Province covering about 50% of the NPR-A is dominated by the Gubik Formation. The word Gubik comes from improper pronunciation of the Eskimo name for Colville River, Kupik (1). Point Barrow divides north of this province into the Chukchi Sea on the west and the Beaufort Sea on the east. The Southern boundary of the province is the Arctic Foothills, and the Colville River is the eastern boundary. The Arctic Coastal Plain has two subdivisions.

a. Coastline of NPR-A

Point Barrow is the divider of the Arctic Ocean coastline of the NPR-A with the Chukchi Sea coastline in the west and Beaufort Sea in the east. The Chukchi Sea coastline has fewer bays and inlets with higher escarpments and coastal bluffs. Narrow beaches contain coarse sediments subject to wind and wave erosion during the summer months. The Beaufort Sea coastline is more irregular than that of the Chukchi Sea, is generally of low relief with mud flats that result from fine material erosion, and erodes more rapidly than the coarse granuled beaches of the Chukchi seashore.

b. Inland Areas

The inland areas of the Arctic Coastal Province are generally flat and without any features. A filigree of meandering streams, hundreds of lakes and lagoons, both drained and undrained, ice wedge polygons and other frost features, sand dunes and other Eolian deposits cover the entire area.

2. The Arctic Foothills Province

This province covers slightly less than 50% of the NPR-A and is divided into two sections.

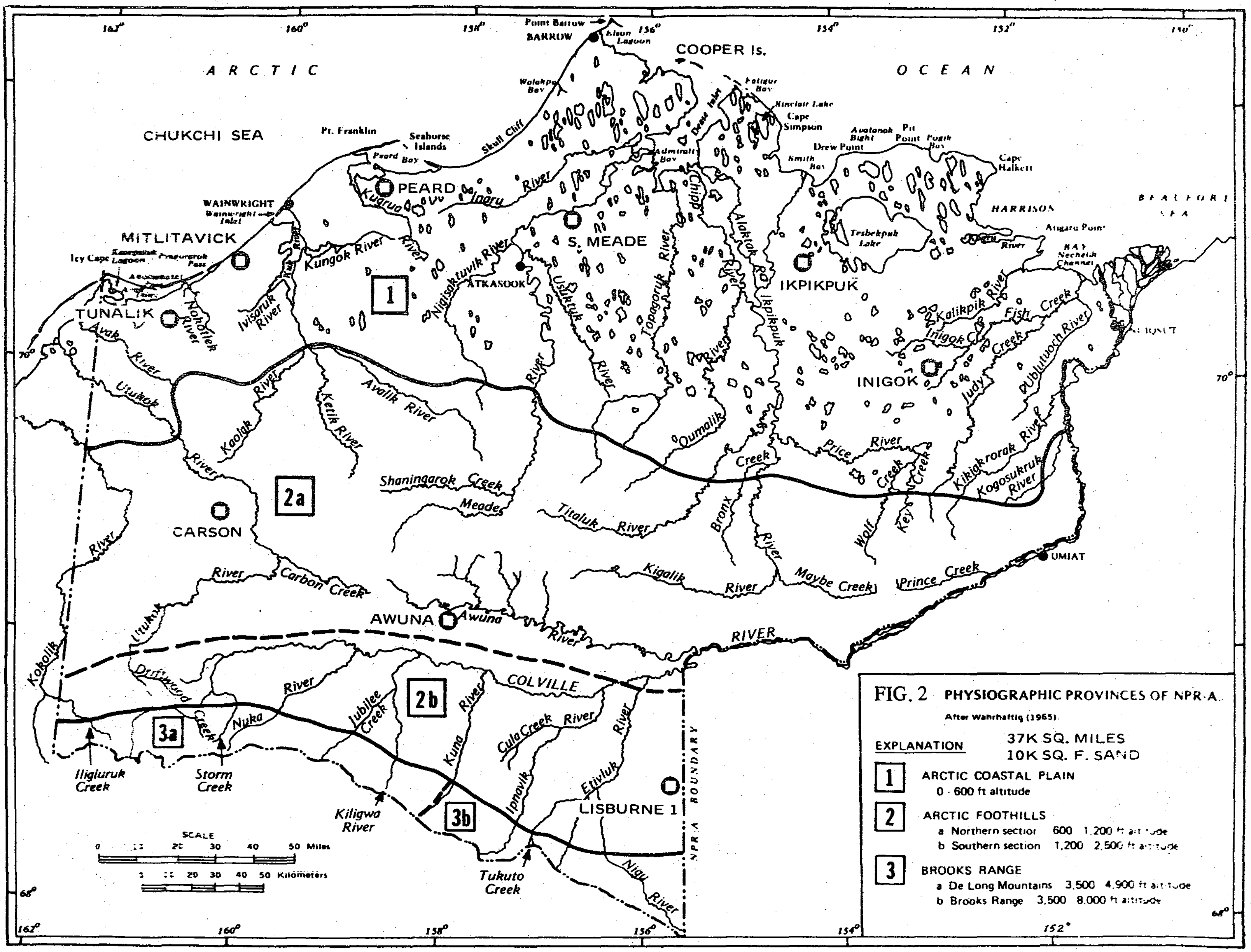


FIG. 2 PHYSIOGRAPHIC PROVINCES OF NPR-A

After Wahrhaftig (1965)

EXPLANATION

37K SQ. MILES
10K SQ. F. SAND

1 ARCTIC COASTAL PLAIN
0 - 600 ft altitude

2 ARCTIC FOOTHILLS
a Northern section 600 - 1,200 ft altitude
b Southern section 1,200 - 2,500 ft altitude

3 BROOKS RANGE
a De Long Mountains 3,500 - 4,900 ft altitude
b Brooks Range 3,500 - 8,000 ft altitude

a. Northern Areas

Terrain here is more complex than that of the Arctic Coastal Plain Province, with tundra covered plateaus, pingos, rolling hills and low east-west oriented ridges. The Colville River, with its north-running tributaries from the Brooks Range, crosses eastward along this province. Other than Colville River, the Utukok and Kokolik Rivers are the only ones that flow across this area.

Drainage patterns in the Northern Foothills flow towards the Arctic Coastal Floodplain or to the south and east toward the Colville River.

Northern Foothills drainage is more complex than the other drainage patterns in the NPR-A. Most of the streams are braided and occupy broad floodplains where spring breakup causes ice jams and gravel deposition along these channels.

b. Southern Areas

The Southern Foothills Province is more irregular than the Northern Foothills with buttes, mesas, ridges and knobs frequently occurring in the area. The Brooks Range marks the southern boundary of the southern section of the Arctic Foothills Province.

3. Brooks Range Province

The Rocky Mountain system extends into northern Alaska and becomes the Brooks Range. In NPR-A the Brooks Range Province is divided into the De Long Mountains and part of the Central Brooks Range, (Fig. 1), where severe glaciations have created aretes (sharp, steep ridges), V-shaped valleys, and cirques.

a. De Long Mountains Section

The boundary between the southern Arctic Foothills Province and the De Long section of the Brooks Range Province is indistinct. All the rivers coming out of the eastern half of the De Long Mountains, with the exception of the Iligluruk Creek of the Kokolik and the Utukok River flow across the Arctic Foothills and the Arctic Coastal Plain provinces into the Arctic Ocean and Chukchi Sea.

b. Central Brooks Range

There is a sharp boundary between the southern section of the Arctic Foothills Province and the Central Brooks Range. The rivers from this area follow the same path as those in the De Long Mountains sector and flow in definite valleys formed by glacial erosions. Many of these valleys

are headed by rock basin (tarn) lakes that do not play any role in the drainage characteristics of this section. The area is dominated by rugged terrain and steep mountains that are entirely north of the tree line. Utukok and Kokolik Rivers are the main drainages in the western quarter of the Central Brooks Range.

B. Climatological Data

In NPR-A, only the village of Barrow and Umiat have long-term climatological data. There are some short-term records available at Nuiqsut, Lonely, and Wainwright. Cloudy days, fog, drizzle, cool winds, and continuous daylight that are characteristics of the Arctic dominate the NPR-A climate. As winter sets in and winds becomes colder, cloudiness decreases, and outside construction becomes more difficult and hazardous due to very cold temperatures and increasing darkness. The climate of the Coastal Area Province is milder than the Arctic Foothills and Brooks Range provinces.

The available climatological data is presented in four groups.

1. Temperature

In the Arctic, thermal energy balance plays an important role. The warmest month of the short summer is July and the coldest of the long winter months is February. The summer temperatures go as high 39°F (4°C) and the coldest winter month recorded is February when the average surface temperatures go down as low as -63°F (-53°C). Coastal area temperatures are milder than the inland temperatures. Chill factor plays a more important role than the air temperatures; extremely low temperatures plus the wind chill factor cause serious problems for construction activities.

2. Precipitation

The only precipitation records on the NPR-A from Barrow and Umiat indicate an average annual precipitation of about 5 in. (127 mm) with frequent light rains in the summer months. In the Brooks Range where there are no weather stations, stream runoff measurements provide a rather crude figure of 20 in. (510 mm) annual precipitation. In NPR-A rains account for the major part of precipitation, although snow may fall throughout the year, with heavier accumulations starting in September. The maximum average snowfall in the Arctic Coastal Province occurs during the months of October and November, the minimum in April and June. More than 12 in. (305 mm) of winter snow is common in NPR-A.

Due to freezing temperatures the absolute humidity in the NPR-A area is low, but the average relative humidity values are 90% to 95% in summer and about 60% in winter.

3. Air Movements
(Only Coastal Plain Province data available)

a. Wind

Measurements in the Coastal Plain Province of the NPR-A indicate that easterly winds dominate this area with annual average speeds of about 10 mph (16k/hr).

b. Strong Winds

In Umiat, strong east and westerly winds during low temperatures cause high chill factors that result in severely cold temperatures as low as -75°F (-60°C).

c. Storms

Records in the Coastal Plain Province indicate that the intense storms are from a westerly direction with gusts up to 55 mph (88 k/hr).

d. Wind Erosion

Wind erosion is less in this area which occur in the Arctic Foothills Province sands.

4. Solar Energy

The areas above the Arctic Circle receive the same amount of sunlight as the lower latitude areas; but within NPR-A, sun strikes the land surface at a relatively lower angle than the latitudes below the Arctic Circle and less energy is received. In NPR-A, the solar energy balance becomes positive by late March or early April and turns to negative in September. From mid-November to late January is the period of nearly total darkness. The Coastal Plains Province receives continuous sunlight in the summer months. Although the sun is above the horizon from May 10 to August 2, stratus clouds are prevalent about half the time decreasing the available sunlight, as indicated by records from Barrow and Umiat.

C. Geophysical Surface Data

The following is not a geological description but is an engineering discussion of the geophysical surface data, other than gravel sizes, of NPR-A.

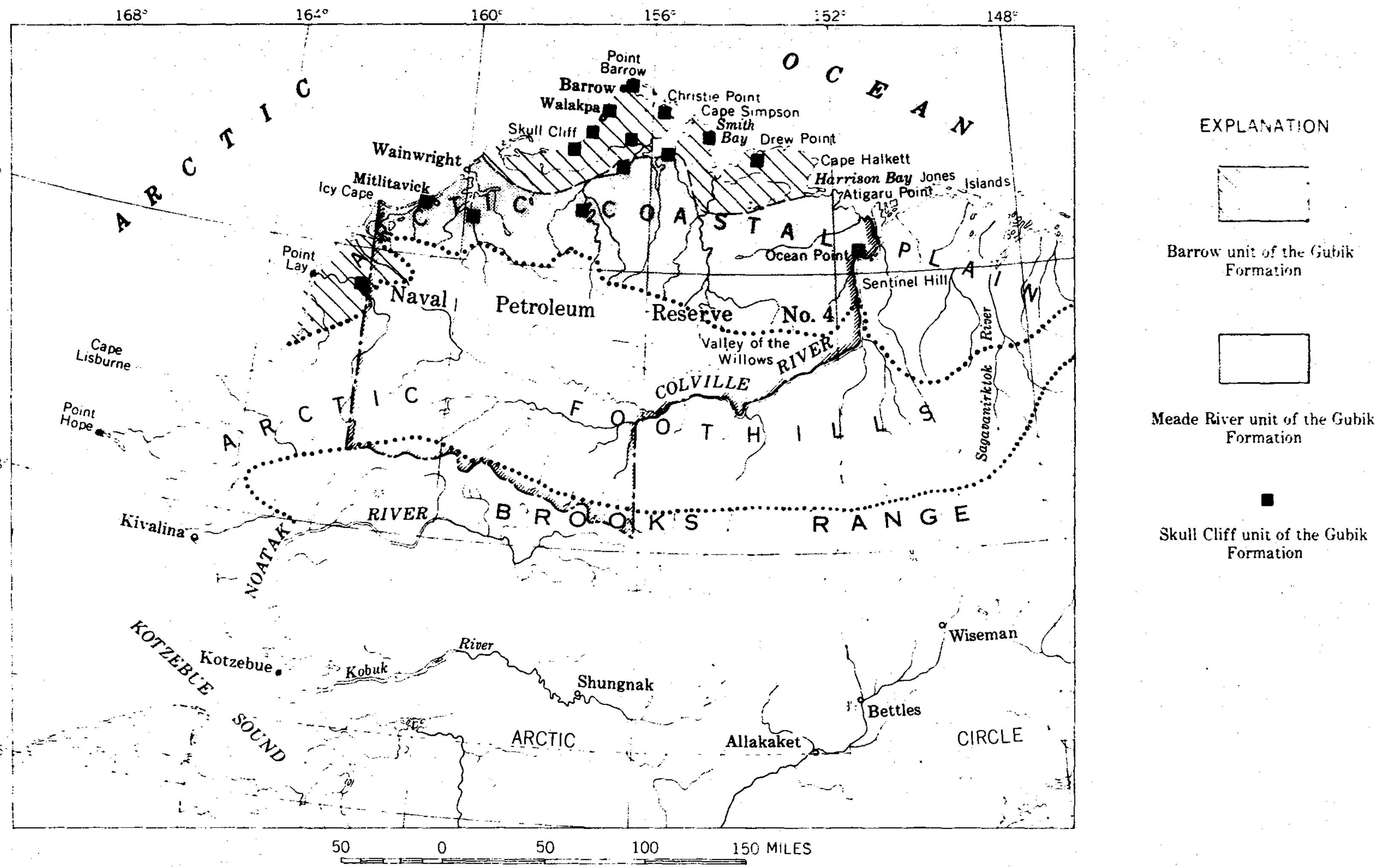


FIG. 3 —Index map of northern Alaska, showing physiographic provinces and distribution of the Gubik Formation west of the Colville River.

Research indicates that geological investigations in the NPRA area have been going on since 1892 (Dall and Harris). The U.S. Navy was given the responsibility for exploration of petroleum resources in 1923 and the Department of Interior was authorized to oversee explorations in 1976.

Arctic Coastal Plain Province materials mainly consist of the unconsolidated Gubik Formation of Quaternary Age, which are interlaced mixtures of coarse to fine gray sand and coarse to fine silts with some clays. Its average thickness is around 50 ft. (15 m), but local thicknesses of about 200 ft. (61 m) have been encountered. The fine-grained materials of the Gubik Formation do not cause any more unusual problems than the similar materials in the continental United States; however, the fact that this formation contains more ice than pore space and is perenially frozen has great engineering significance.

The dominant mineral of the formation is quartz, and chert is abundant locally only with some angular and sharp granules. These quartz granules are mostly well-rounded, clear and colorless with some black, brown, and pinks. Some sharp and angular granules are also present. The next dominant mineral, chert is well-rounded, smooth, and polished as well as angular, fresh grains with black, brown, gray, green, tan, brown, and cream colors. Other minerals, which constitute a maximum of 10 percent of the total, range from well-rounded and polished to angular and fresh. The following is a discussion of available materials in NPR-A provinces (6).

1. Arctic Coastal Plain Province

   This area is divided into three main units Fig. 3, that contain materials with the most organic content of the three provinces.

   a. Skull Cliff Unit. This is the oldest of the province units consisting of poorly graded sediments from clay to cobble sizes 6 in. (15 cm) with an organic content of 5-10 percent. It is black to dark gray in color and goes down to maximum 20 ft. (6.1 m) depths. Typical gradation curves are shown in Fig. 4,5 (2).

   b. Meade River Unit. This unit covers more than half the coastal area of the Coastal Plain Province. It is light colored and the most uniform graded unit within the Gubik Formation. It consists of two elements. The first one is a clean, well graded marine sand that makes up the dunes in the area, and the second one is a well-graded uniform silt resembling loess than has 62-83 percent between the effective diameter sizes 0.101 and 0.05mm. The organic contents of these two materials range from 46 percent around the Topagoruk River to 0.9 percent in the sands of the Admiralty Bay and Atigaru Point.

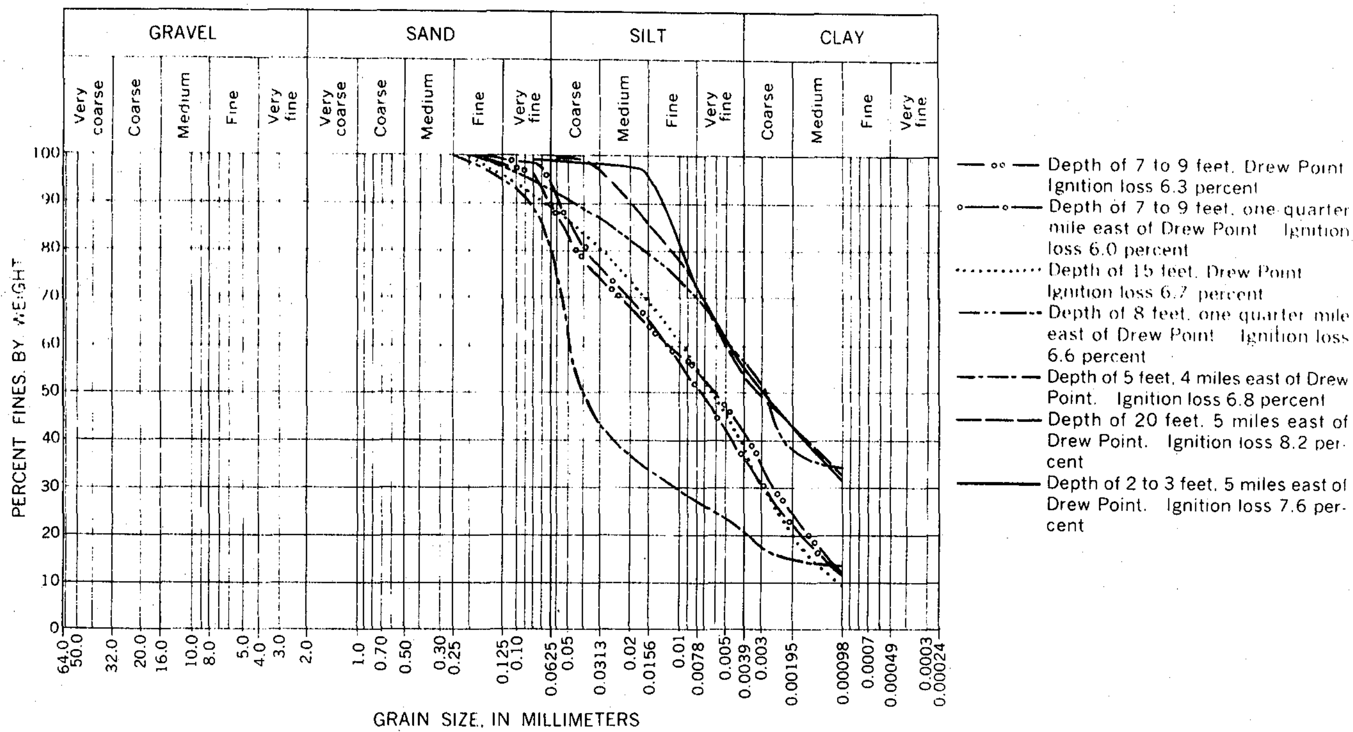


FIG. 4 —**Size-grade cumulative curves of the Skull Cliff unit of the Gubik Formation from Drew Point area.**

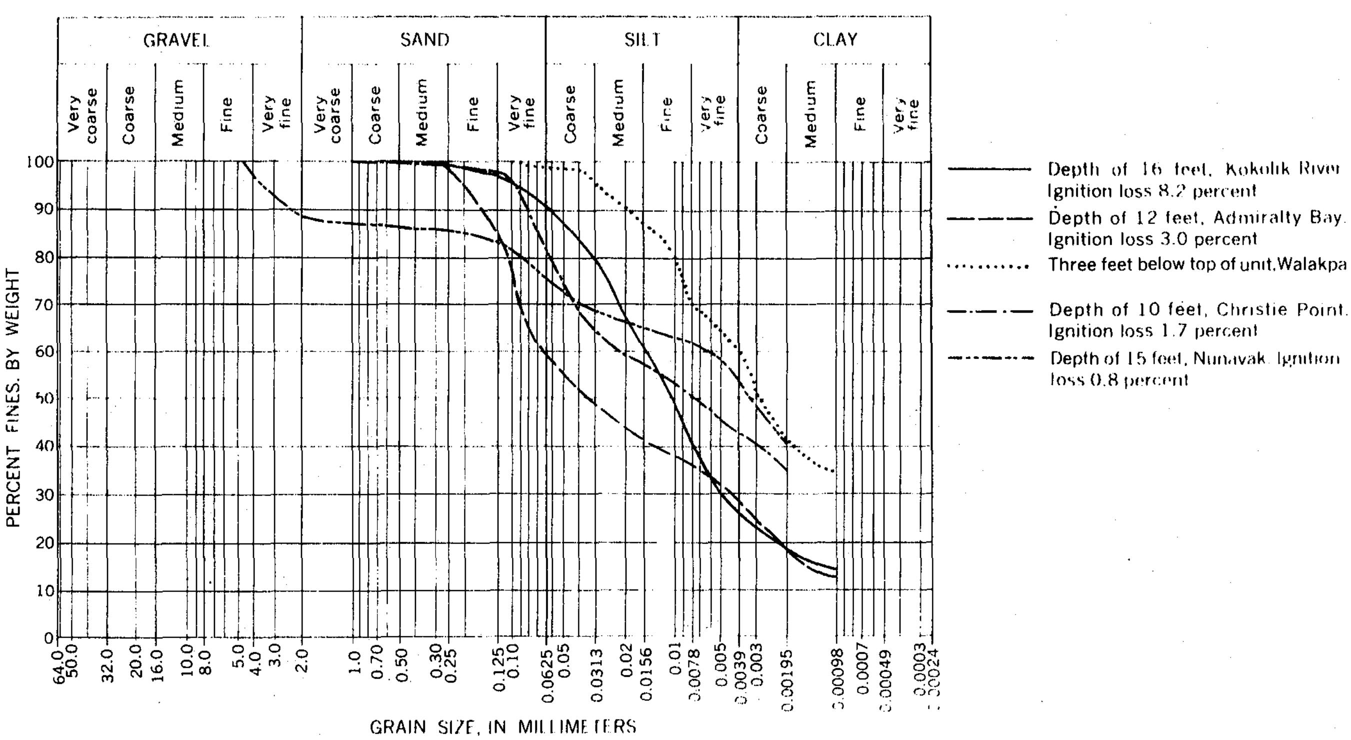


FIG. 5 —**Size-grade cumulative curves of the Skull Cliff unit of the Gubik Formation from Kokolik River, Admiralty Bay, Walakpa, Christie Point, and Nunavak.**

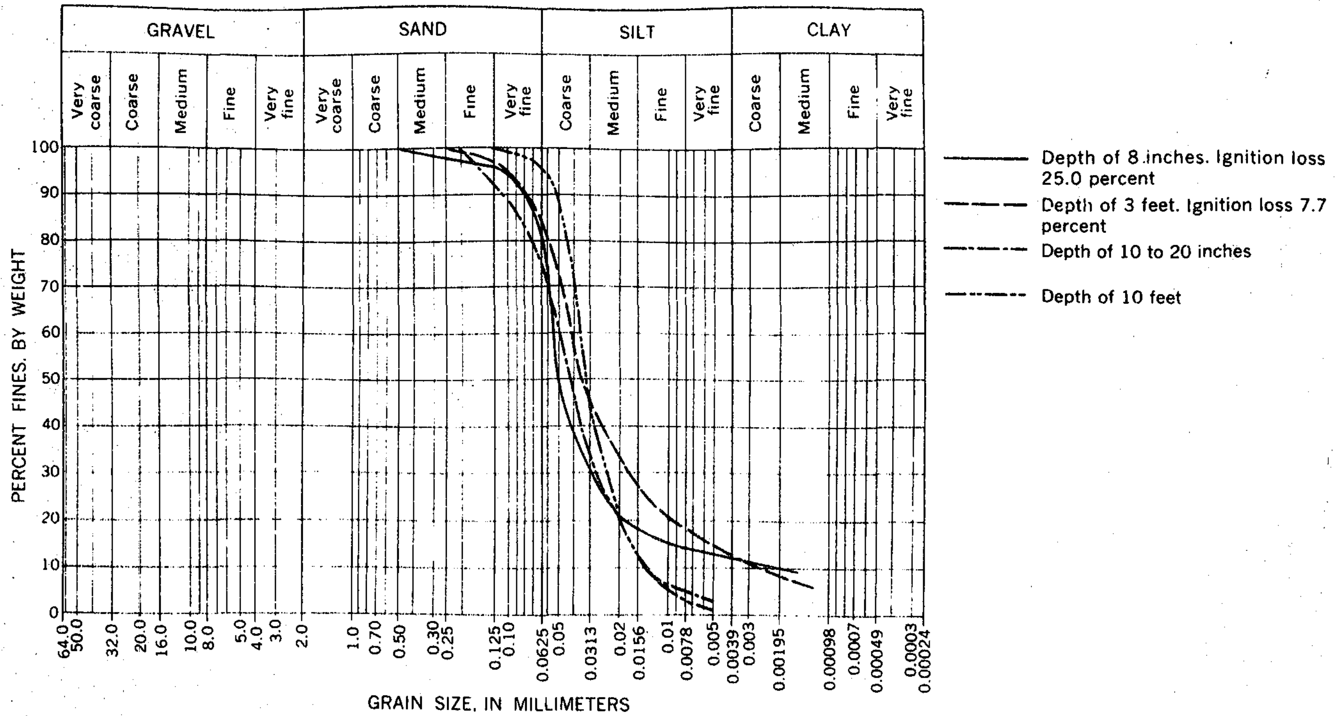


FIG. 6 —Size-grade cumulative curves of the Meade River unit of the Gubik Formation from Sentinel Hill.

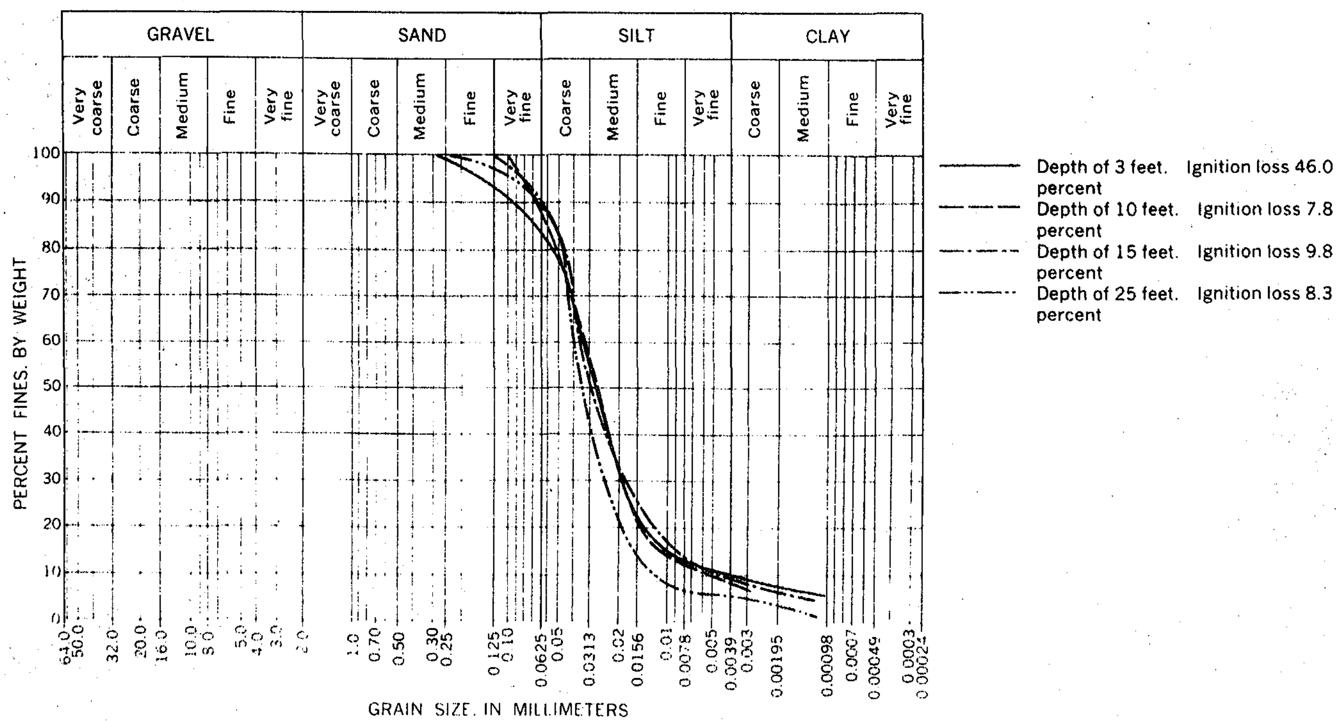


FIG. 7 —Size-grade cumulative curves of the Meade River unit of the Gubik Formation from the Topagoruk River.

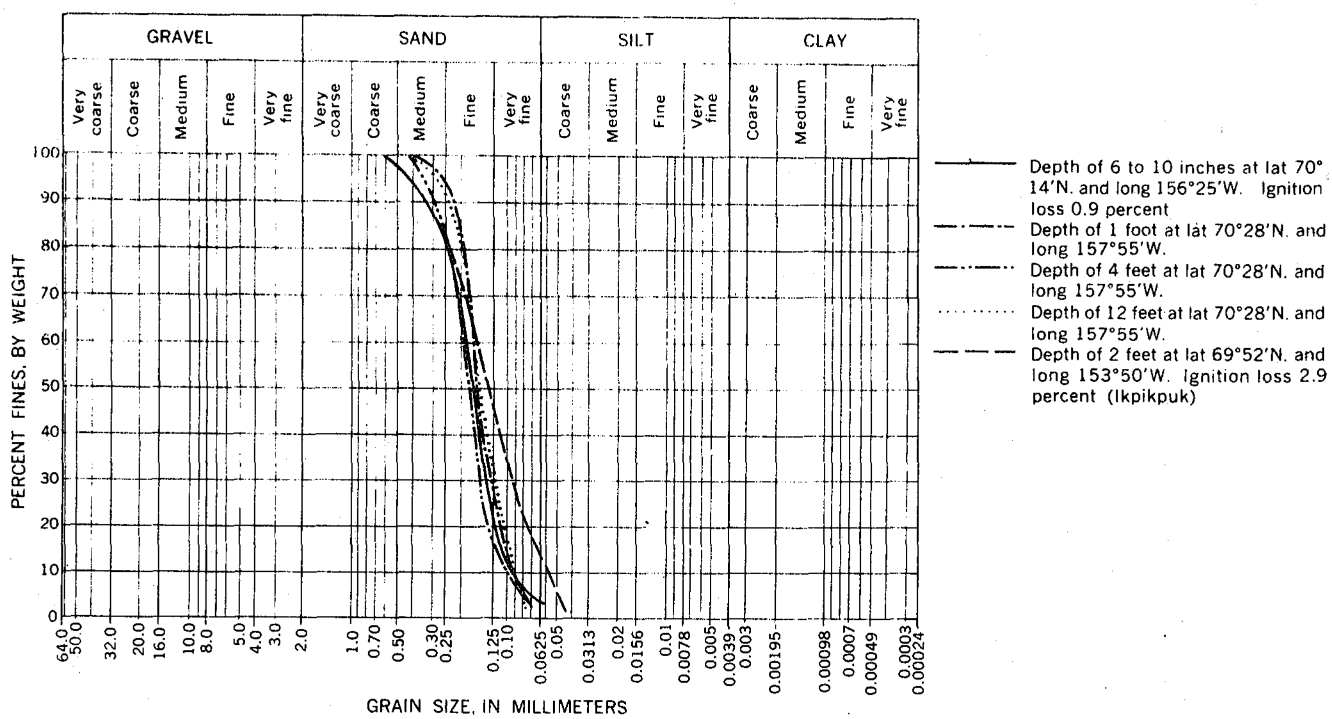


FIG. 8 —Size-grade cumulative curves of the Meade River unit of the Gubik Formation from the central part of the coastal plain and Ikpikpuk.

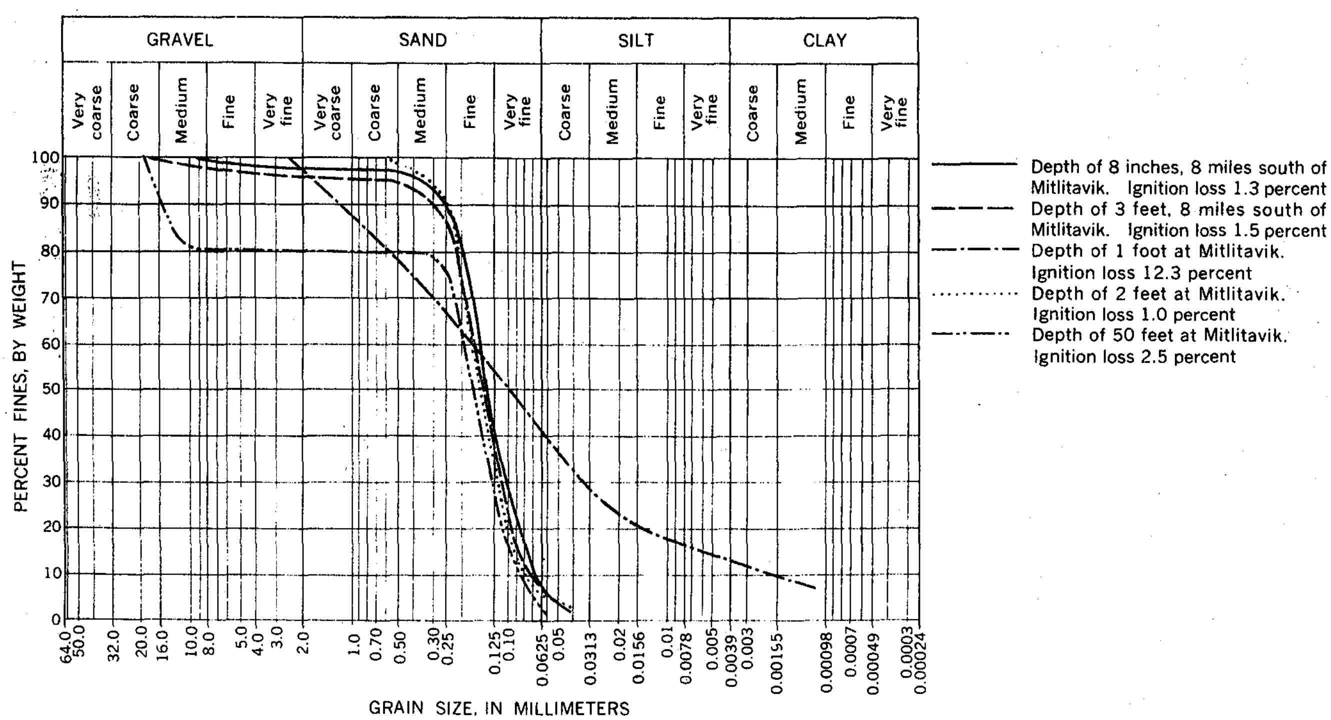


FIG. 9 —Size-grade cumulative curves of the Meade River unit of the Gubik Formation from the vicinity of Mitlitavik.

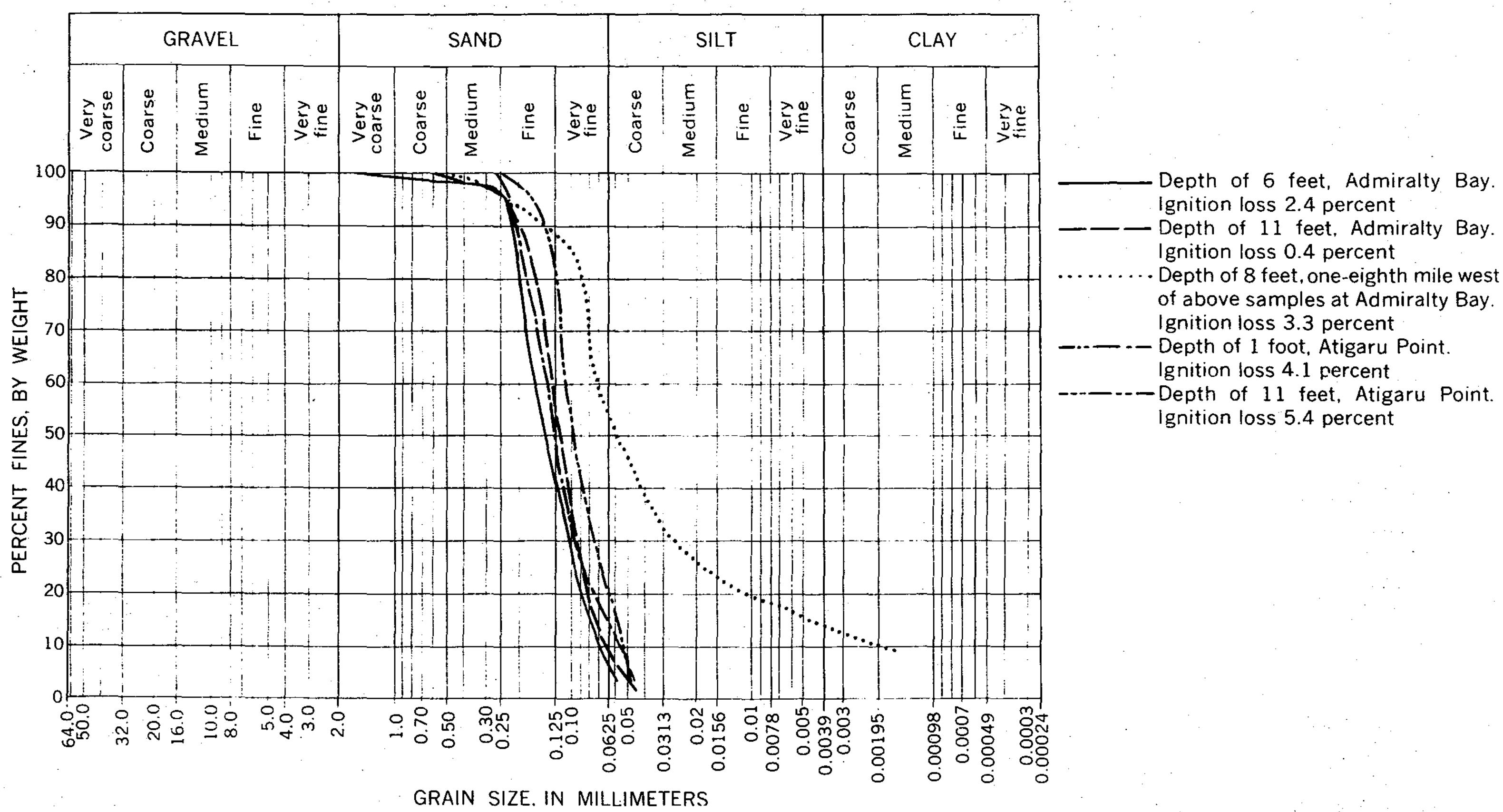
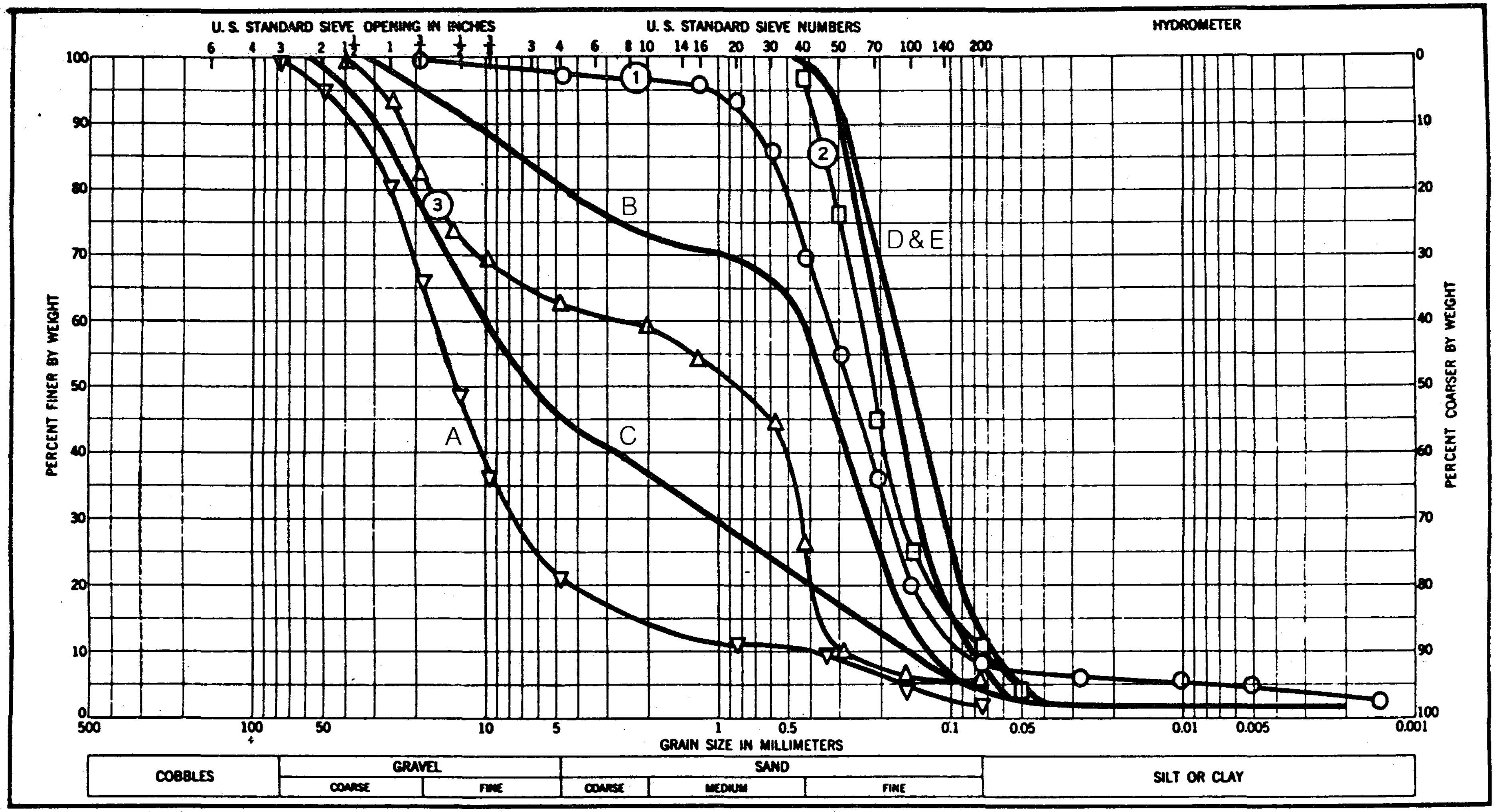


FIG. 10 —**Size-grade cumulative curves of the Meade River unit of the Gubik Formation from Admiralty Bay and Atigaru Point.**



1 – ○ TEST SECTION (SAND SP)
2 – □ CRREL TEST WET SAND
3 – △ TEST SECTION GRAVELLY SAND
A – ▽ COLVILLE RIVER GRAVEL, CRREL
B KIKIAKRORAK R., SANDY GRAVEL
C JUDY CREEK, GRAVELLY FINE SAND
D & E INIGOK, SILTY FINE SAND

FIG. 11 **TYPICAL AREA MATERIALS**

Sands of this unit occupy the central part of the Coastal Plain Province west of the Colville River, specifically the area around the Meade and Ikpikpuk Rivers. Silts are encountered in the southern and southeastern parts of this area and along the Colville River. The Meade River Unit has a maximum reported thickness of 180 ft. (55 m) west of the Inigok Creek, with an average thickness of 50-100 ft. (15-30 m), (See Fig 6 to 11) (2,19).

c. Barrow Unit. This is the youngest of all the three units and contains well-graded mixtures of clays, silts, sands, and gravels. Organic matter and ice are abundant in the upper parts with ice occuring as wedges that go down 30 ft. (9m). Lenses of greatly varying materials from clay sizes to gravel, ranging from a few inches to several feet in thickness and from 20 ft. (6 m) to many miles in length, are common (Fig. 12 to 18).

2. The Arctic Foothills Province

Soils on the north edge of the foothills are composed of medium to fine-graded sands, the result of frost action and Eolian processes; exceptions are localized quartz sands and conglomerates in the lower areas (4,5).

Dominant minerals are quartz with well-rounded as well as angular grains, followed by chert and some accessory minerals. Along the Colville River in the east, the materials are much finer and turn into loess with effective sizes between 0.01 and 0.05mm diameter, which are light yellow-brown, calcareous, generally massive and structureless. This upland silt dominates the northern sections of the province from the Umiat area to the southern end of the Avak River and the northern part of the Utukok River flowing within the province. The southern part of this province is mostly undifferentiated bedrock, covered with a very thin layer of surfacial deposits. The undifferentiated bedrock in this section consists of shale, graywacke, silt stones, sandstones, and conglomerates.

Within the Arctic Foothills, the area north of the Colville River is mostly composed of sandstones, conglomerates, and shales existing around 500 ft. (152 M.) elevations. Limestone and chert exist south of the Colville River from the Ipnavik River to the Nuka River region between elevations of 1500 to 2000 feet (45 - 600 m.). From Kuna River westward, at about 2000 feet (600 meters) elevation, chert and shale with few fine-grained gray limestone beds dominate the area. Wellbedded black chert and gray limestone with black chert nodules are observed around 2000 ft. (600 m.) elevations from Iteriak Creek of the eastern branch of the Colville River to the Nuka River on the west. Limestone with local black chert nodules and sandy limestone with local sandstone and shale start to appear from 2000 to 2500 feet (600 - 750 m.) (14).

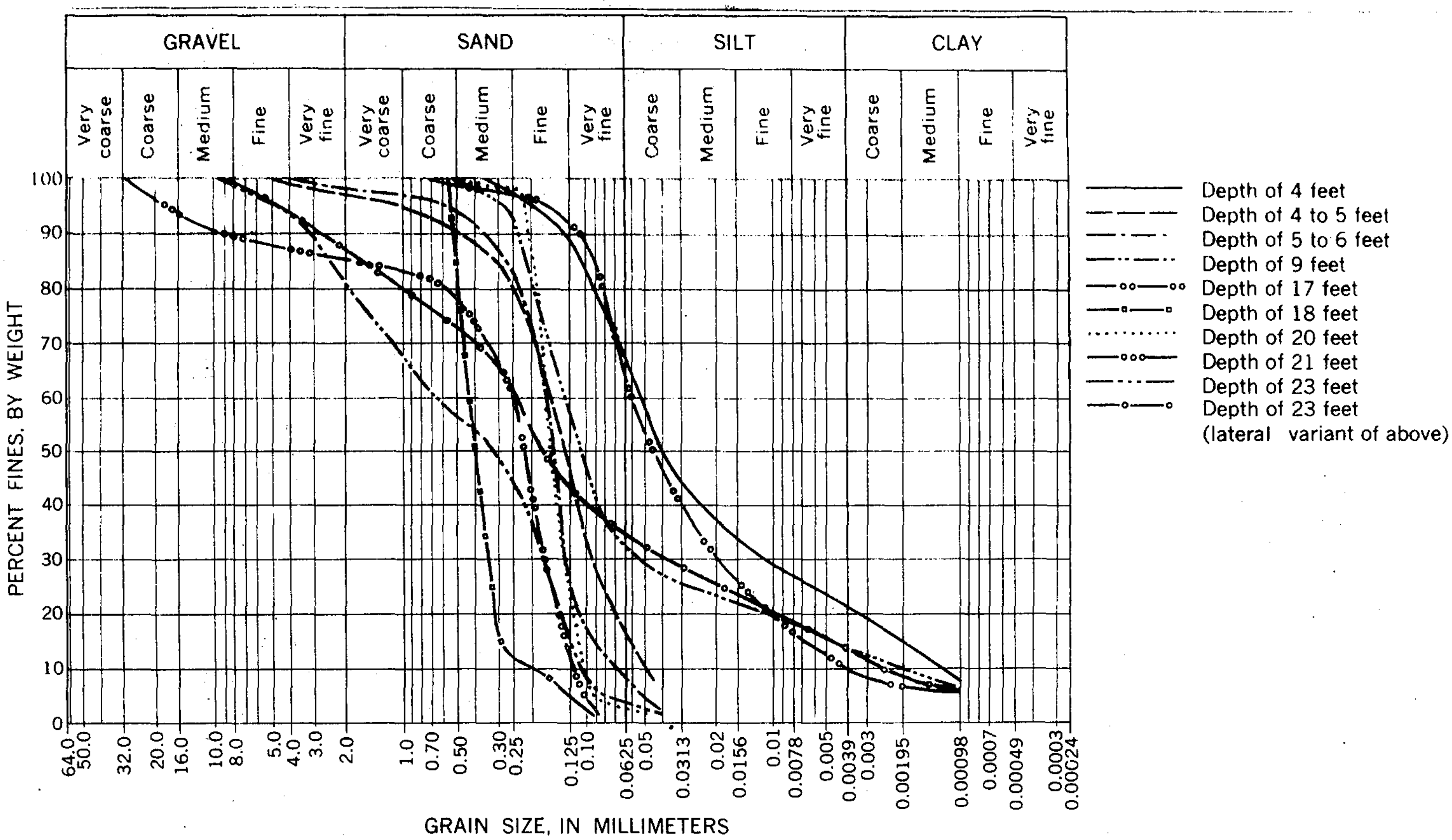


FIG. 12 —**Size-grade cumulative curves of the Barrow unit of the Gubik Formation from Walakpa.**

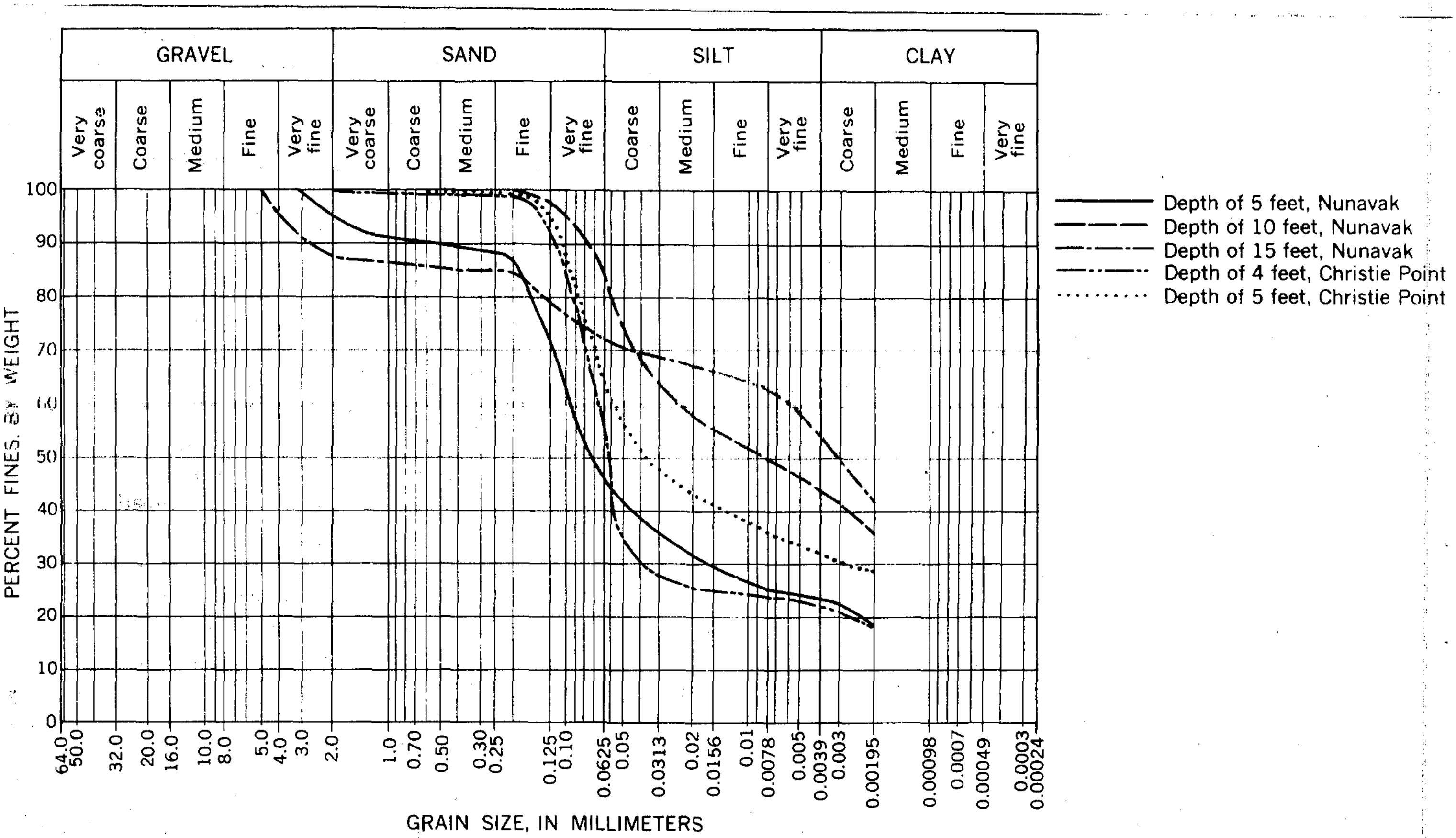


FIG. 13 —**Size-grade cumulative curves of the Barrow unit of the Gubik Formation from Nunavak and Christie Point.**

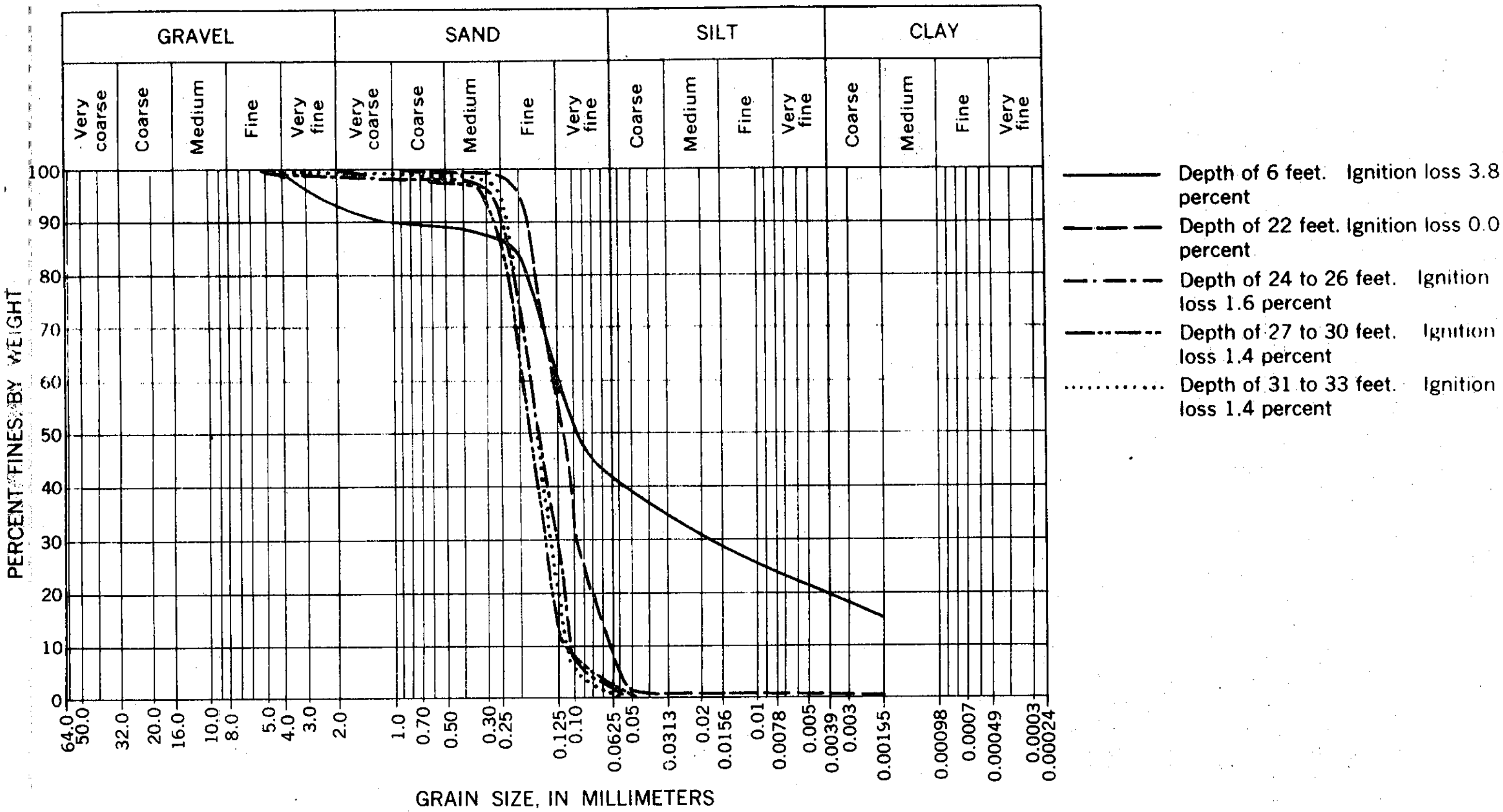


FIG. 14 —Size-grade cumulative curves of the Barrow unit of the Gubik Formation, Barrow area, from airbase ice cellar.

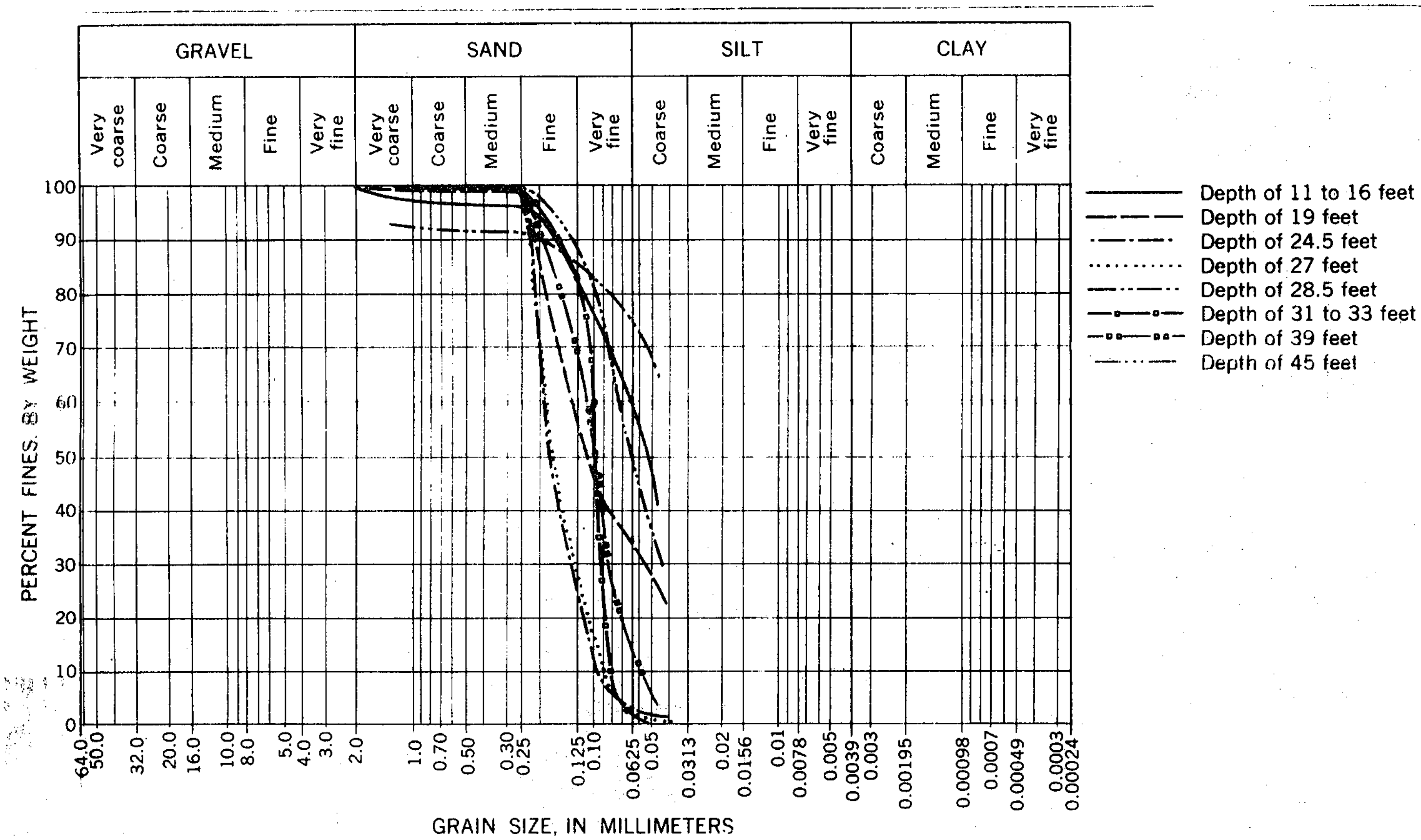


FIG. 15 —Size-grade cumulative curves of the Barrow unit of the Gubik Formation from Barrow area drill cores.

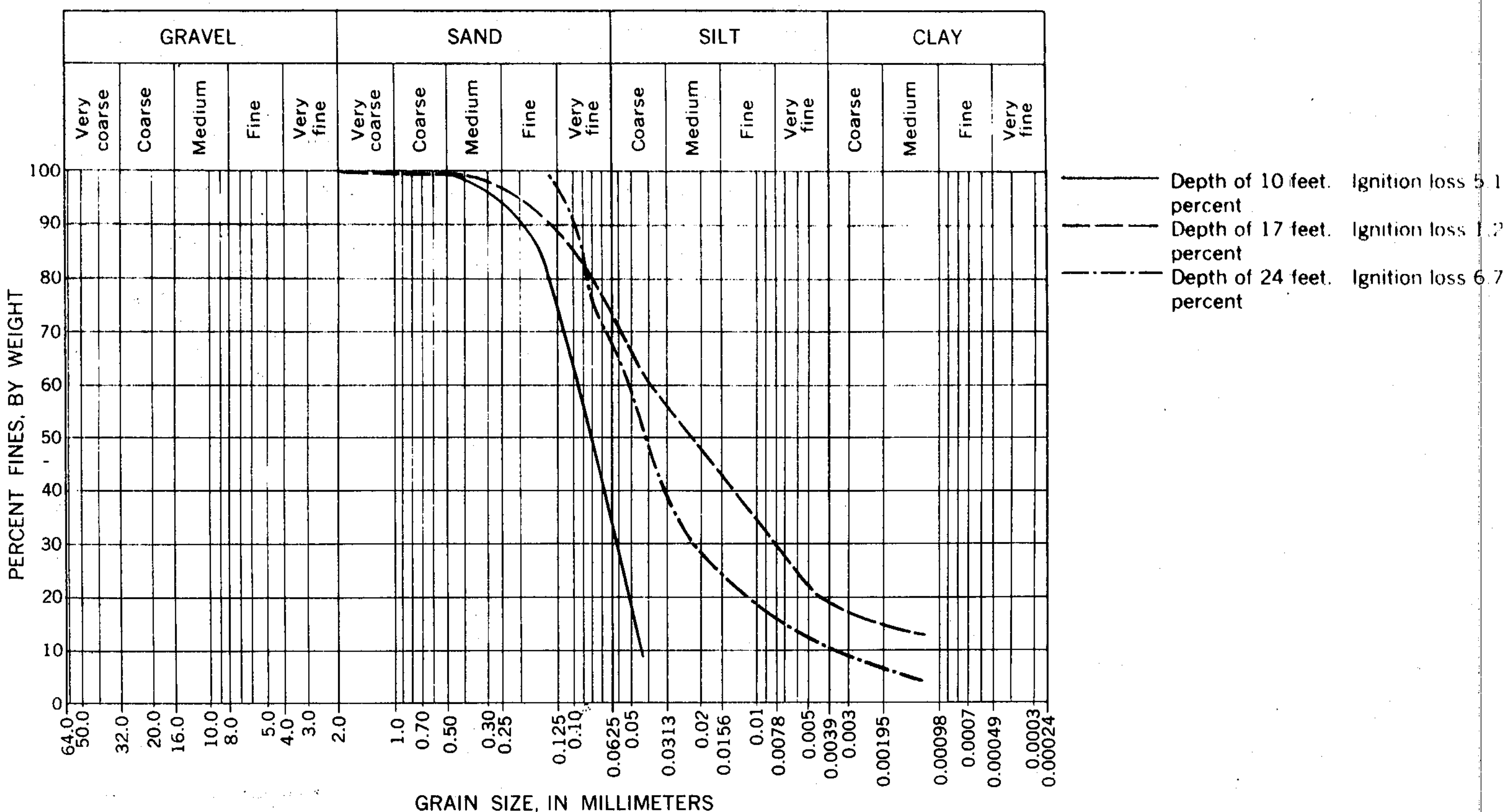


FIG. 16 —Size-grade cumulative curves of the Barrow unit of the Gubik Formation from Teshekpuk Lake.

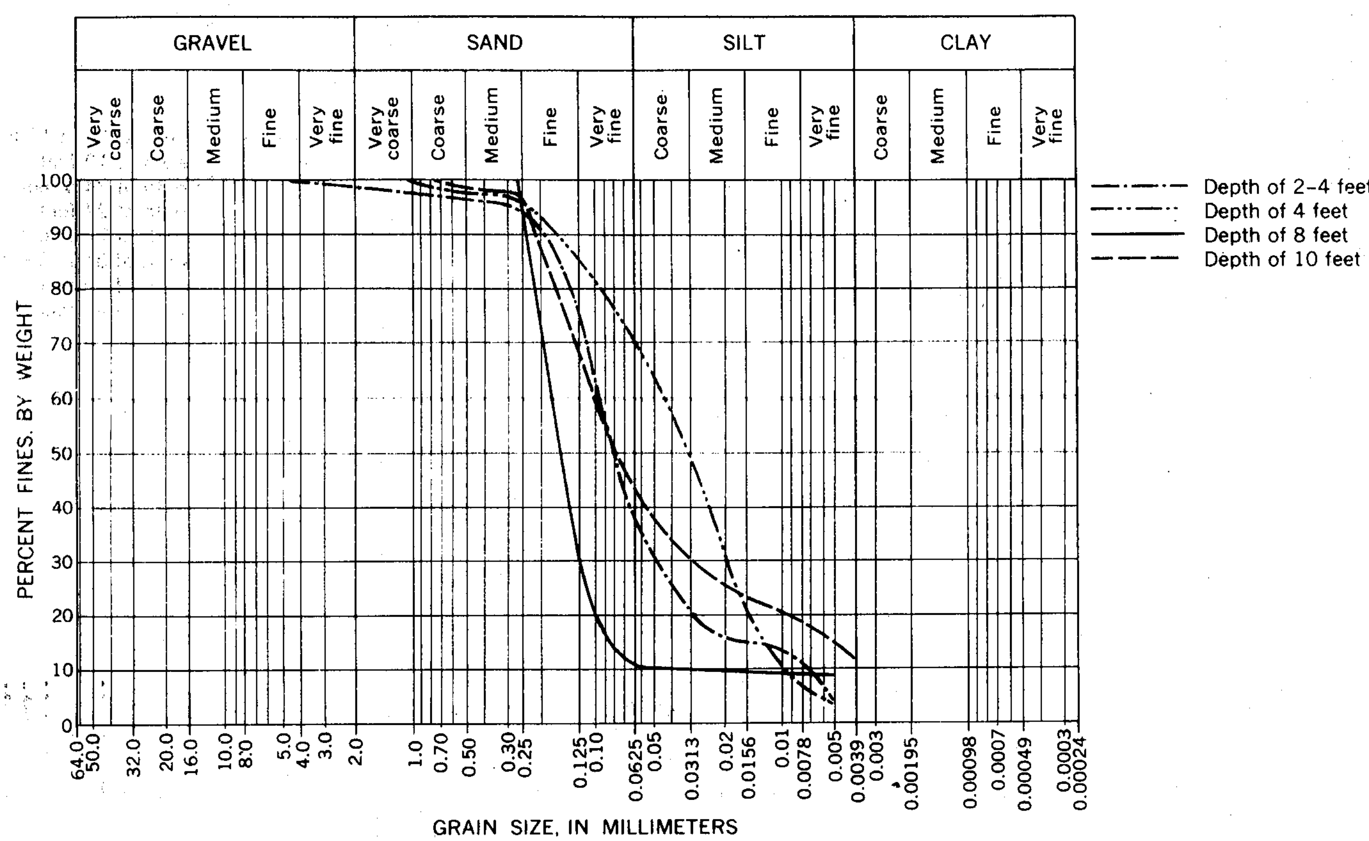


Fig. 17 .—Size-grade cumulative curves of the Barrow unit of the Gubik Formation from Peard Bay.

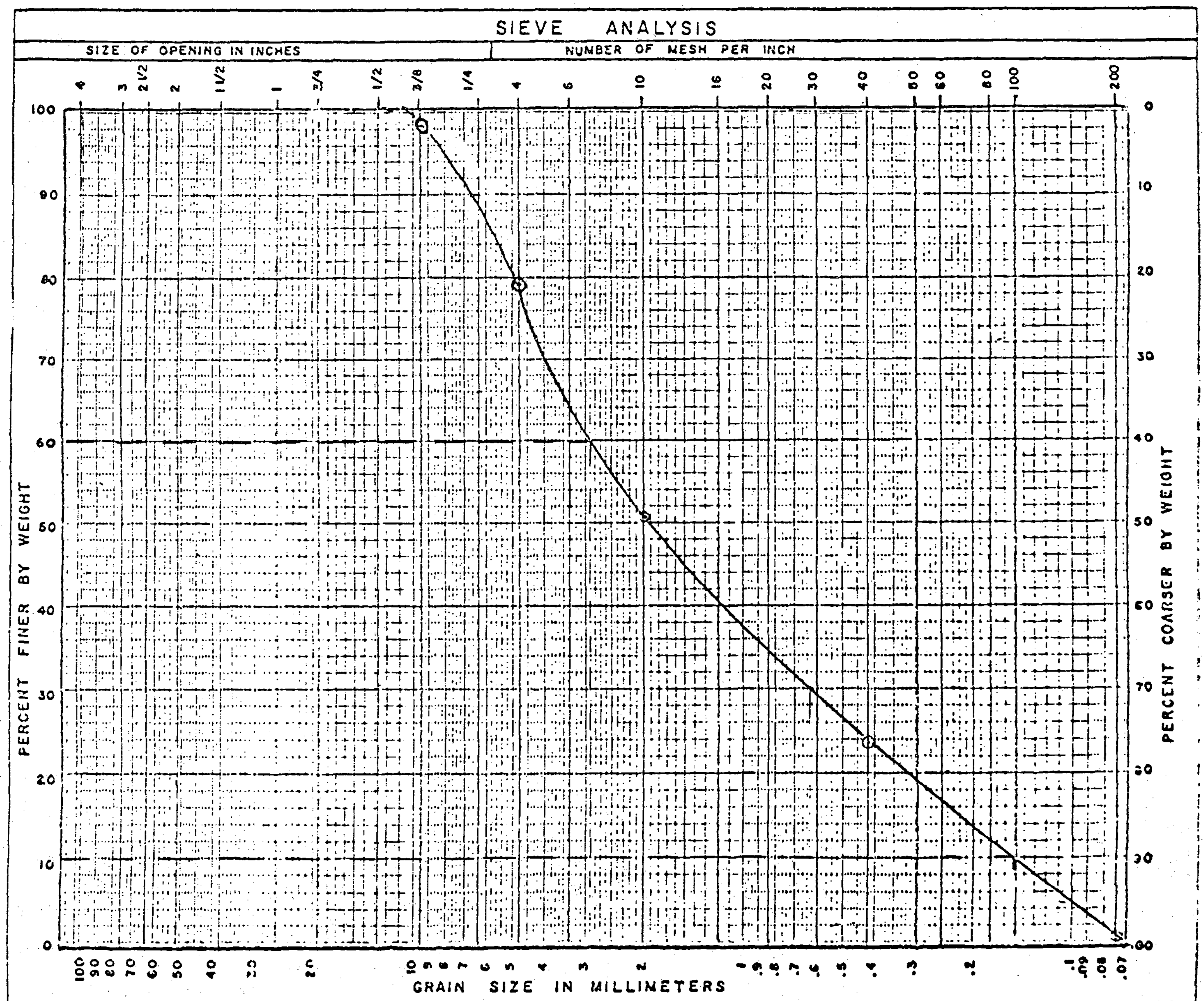


FIG. 18 COOPER ISLAND SIEVE ANALYSIS

3. Brooks Range Province

The materials other than gravel in the northern section along the parts of the Colville River that lie in this province, are mainly undifferentiated bedrock with localized areas of sands (3). In the south section of this province, older glacier till, consisting of effective diameters ranging from 0.5m to 2.0 m., dominate. The highly variable silt content of this material has not been verified (13).

D. Permafrost

Permafrost is defined as a thermal condition of any earth material which has remained continuously below 32°F (0°C) for a minimum of two years. The volume of ice in permafrost materials can be several times the volume of other components, approaching pure ice; whereas, at the other extreme permafrost consisting mostly of clean gravels may contain very little ice. Unfrozen moisture can exist in permafrost due to solute concentrations, high confining pressures, and particle surface forces.

NPR-A lies entirely within the zone of continuous permafrost, which has varying seasonal temperatures and depths with recorded temperatures ranging from -9.5°C near Barrow to about -6.5°C around Umiat. The deepest permafrost recorded is at 1,330 ft. (405m) near Barrow, and the NPR-A average permafrost thickness is about 780 ft. (24m). Polygonal ground formations, pingos, and thaw lakes are characteristics of the permafrost areas in NPR-A. Solifluction is the term given to the slow downgrade movement of loose, saturated, fine sands and silty surface materials. These movements can occur from 3° to 10° slopes at the rate of 0.4 in. (10mm) annually. Lobes and sheets are common features of solifluction in the Arctic Foothills and Brooks Range.

The thawing of ice-rich, fine-grained soils, such as fine sandy silts, or silty fine sands, usually cause subsidence or slumping reduction of the sheer strengths of the soils brought on by the slow dissipation of excess pore pressures that cause slow failures, as well as reduction of the bearing capacity of these soils, lead to significant engineering problems in the Arctic.

E. Water Resources

The hydrologic regime of the NPR-A is greatly affected by surface storage and is dominated by summer rains, spring breakup, and snow melt. Snow melt causes floods in the spring and rainstorms causes floods in the summer, especially in the Brooks Range rivers where heavy summer rainfall combines with the snow melt. Plentiful water is only available during the short summers, and groundwater discharge and recharging is severely limited by the permafrost conditions. Water quality is usually acceptable when standard treatments are utilized, with the exception of the spring breakup periods.

NPR-A water resources fall under two main groups according to the extremely limited hydrology data. Only estimated values that have been developed by statistical methods are available (7). Annual runoff figures for the hydrological provinces are:

Coastal Plain Province average	0.5 ft.^{3}/sec./mi^2 (0.005m^3/sec./km^2)
Northern part of Coastal Plain Province	0.2 ft.^{3}/sec./mi^2 (0.002m^3/sec./km^2)
The mean annual PEAK runoff for the Coastal Plain Province	10 ft.^{3}/sec./mi^2 (0.1m^3/sec./km^2)
Southern section of the Foothills and Brooks Range	2 ft.^{3}/sec./mi^2 (0.02m^3/sec./km^2

The mean annual runoff for the mountainous regions can be as high as 50 ft.^{3}/sec./mi^2 (0.5m^3/sec./km^2) (8).

The available estimates indicate that no flow occurs in the western rivers of the coastal plain from October to May but during June, 74% of the total annual runoff, 132,000 ft.^{3}/sec. (3,700m^3/sec.), is discharged.

1. River and Streams

NPR-A rivers and streams are classified into three physiographic catergories. The first category is Brooks Range and Northern Arctic Foothills rivers with great discharges (Colville and Utukok). This is followed by the Arctic Foothills rivers with medium discharges and lengths. The third category is the short rivers originating in the Arctic Coastal Plain, which have small discharges.

2. Lakes and Groundwater

Near the coastline of the NPR-A, there are four lakes that are more than 10 mi^2 (25km^2) in area.

Teshekpuk	315 mi^2 (815km^2)	46 ft. maximum depth (14m)
Sugovoak	21 mi^2 (954km^2)	8.1 ft. maximum depth (2.5)
Tusikvoak	13 mi^2 (34km^2)	8.9 ft. maximum depth (2.7m)
Naluakruk	12 mi^2 (31km^2)	11.7 ft. maximum depth (3.6m)

Water depth is a major factor in determining the possibility of using a lake for winter water sources during the Arctic construction seasons. The quality of lake and ground waters in the NPR-A are usually of the sodium chloride type (9,10).

III. ENGINEERING CONSIDERATIONS OF ALTERNATE DESIGNS

NPR-A has a harsh and extremely delicate environment. It is not only imperative but of extreme importance that any engineering approach for the proper design, construction and maintenance of embankments should consider the area's unique environmental and geological characteristics. A mobilization of the engineering knowledge and experiences to work with rather than work against the harsh but fragile environment of the NPR-A is the primary element of the engineering considerations in this region.

The "no-gravel" design alternates are classified in six main sections.

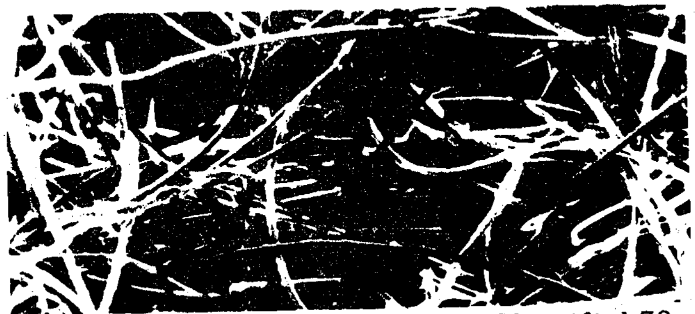
A. Sand and silts with synthetic fabrics, membranes, insulating materials, and chemical binders:

1. Synthetic Fabrics and Membranes.

More than ten companies around the world produce synthetic non-woven fabrics of which the United States consumes about \$1.3 billion annually. The four major production processes are needle-punched, spun-bonded, melt-bonded, and resin-bonding (20).

There are over 50 different trademarks and qualities woven, non-woven, porous, and impervious synthetic fabrics and membranes in use (Fig. 19, 20). The concept of using these synthetic fabrics and membranes in environments and with materials similar to those that exist in NPR-A is not new (15 to 20 and 37). High bearing strengths and greater stability are accomplished by using synthetic fabric layering plus membrane encapsulation of fine soils to increase their bearing strength and stability, while preventing moisture infiltration into the (Fig. 21). The bearing strength and stability is increased by reducing the total embankment thickness through a layering system of synthetic fabrics that cut through the failure planes. These fine materials are placed and compacted at slightly below optimum moisture contents to provide high bearing strengths. Moisture infiltration into them is arrested by the membrane encapsulation, that forms a closed system not subject to detrimental frost heaving and boils during and after freezing, and thawing periods. The choice of synthetic fabric and membranes will depend upon the soils characteristics and the loading conditions on the embankment. Figure 21 shows a use of synthetic fabrics, membranes, and foam insulation in a typical embankment section. Typical physical properties of these fabrics are listed in Table 1. For fine-grained soils in the NPR-A, the use of insulation to form an ice box effect at the bottom and around the main embankment section is recommended.

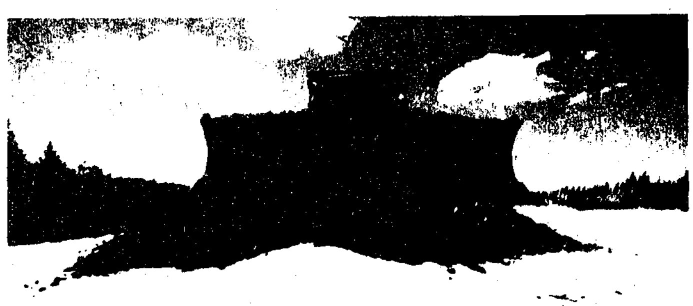
FIG. 19



Magnified 30x

GEOTEXTILES. Spun-bond filaments.

FIG. 20



GEOTEXTILES. During Installation

2. Insulating Materials

a. Polystyrene Insulation Boards.

Knowledge accumulated from actual tests and experiences in the NPR-A indicate that the use of insulation between the embankment and the tundra surface, as well as around the embankment, will provide an all seasons structure. In regions of NPR-A similar to the Inigok area, tests and heat transfer studies show that the settlements created by the thawing of the silty sands of the area, in either cuts and/or fills, "...can be limited or entirely eliminated by the use of insulation" (21, 22, 37).

Using the expanded polystyrene bead boards, the recommended insulation over the tundra under the embankment would be a minimum 4-inch (10 cm.) thickness of 60 psi (4.2 kg/cm^2) polystyrene insulation board with a "k" value of 1.15 Btu/ft.hr. °F (2.0 w/m°) (22, 36). The preferred techniques to arrive at a suitable method for subgrade preparation before placing insulation are:

(1) Place a leveling course of NSF sand 6 in. (15 cm) in thickness over the tundra and snow.

(2) Roll the snow with 10-ton rollers and back-drag with a dozer.

The physical properties of a typical insulation board extruded from expanded polystyrene is shown in Table 2.

Every attempt should be made to minimize the disturbance of the tundra vegetal mat to utilize its natural insulation properties. Insulation damage can result from surface irregularities of the prepared subgrade surface. The above mentioned techniques must be employed to prevent this. Winds which are quite frequent in the NPR-A, may cause problems in the placement of the insulation over subgrade; these may be eliminated by the use of steel, wood, or other kinds of pins (23). The maximum moisture absorption of the insulating materials should not exceed 0.25% by volume. Laboratory test results of the insulation samples taken from the bottom of embankments constructed in regions similar to NPR-A, indicate that the insulation used in these areas are still in good condition. Thermistor records of these embankments show that the subsurface soils are still in a frozen state, indicating an increase in the strength of the adfreeze bonds and good bearing capability (22). The joints of the

NOT TO SCALE

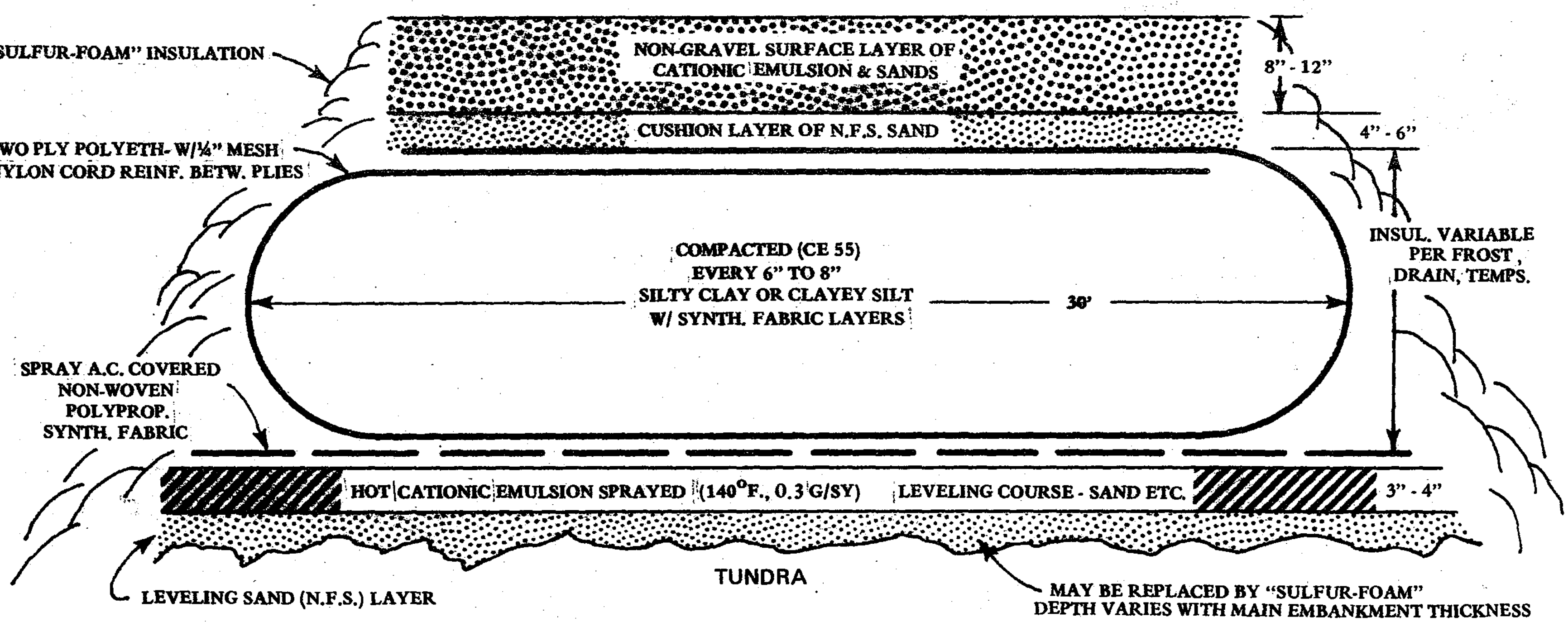


FIG. 21 TYPICAL PREFERRED SECTION

TABLE 1 Physical and Mechanical Property Comparison of Fabrics

Section Number	Fabric	Style	Manufacturer or Agent	Fiber Type[a]	Process Type[b]	Physical Properties: Weight[c] (oz/yd²)	Physical Properties: Thickness[d] (mils)	Physical Properties: EOS[e] (Sieve Number)	Mechanical Properties: Grab Strength[f] (lb)	Mechanical Properties: Elongation[g] (%)	Mechanical Properties: Burst[h] (psi)	Mechanical Properties: Trapezoidal Tear[i] (lb)
2.5.1	Adva Felt	TS200	Advance	1	1	6.0	80	90	115	89		
		TS300				8.0	130	70	225	101		
		TS400				10.5	170	60	300	110		
2.5.2	Bay Mills	154	Bay Mills	4	4	9.7	14					
		144				6.0	9					
		610				2.5	4					
		196				32	45					
2.5.3	Bidim	C22	Monsanto	2	1, 2	4.5	60	50*	115	85	225	62
		C28				6.0	75	50*	160	80	360	93
		C34				8.0	90	70*	255	75	400	125
		C38				10.0	110	100*	300	65	500	170
		C42				16.2	190	100*	610	60	850	250
2.5.4	Cerex		Monsanto	3	1	0.3	2.3		8		17	3.4
						0.4	2.5		12		20	4.3
						0.5	3.2		16		24	4.5
						0.6	3.4		21		29	5.5
						0.7	3.7		27		33	6.3
						0.85	4.2		32		36	6.5
						1.0	4.8		41		40	8.0
						1.5	7.1		53		52	11.0
						2.0	8.7		70		65	14.0
2.5.5	Cordura	500	duPont	3	4	6.3	17		413		495	
		1000				9.9	27		567		680	
2.5.6	Enkamat	7010	American Enka	3	5		354			50		
		7020					710			50		
2.5.7	Fibretex	320	Crown Zellerbach	1	1, 2	9.4			125	130		
		420				12.4			150	150		
		600				17.7			250	160		
		200				5.9						
		300				8.8						
		400				11.8						
2.5.8	Filter-X		Carthage Mills	5	4	11.6		100	200	23	260*	70*
2.5.9	Laurel Cloth	A	Laurel Plastics	1	4	7.2	17	100	400	33	528	90
		B				6.3	22	40	280	40	520	
2.5.10	Mirafi	140	Celanese	5	3	4.1	30		120*	130*		65
		500X		1	4	4.0	25		200*		325	
		100X		1	4			40	120*		200	65
2.5.11	Monofelt		J. P. Stevens	1	5	5		90	130	72	230	
2.5.12	Monofilter		J. P. Stevens	1	4	7	20	40	347		532	
2.5.13	Nicolon	66339	U.S. Textures	5	5		30	40	260	30	500	
		66373					30	35	240	32	500	
		66424					24	70	240	30	>600	
		66392					24	70	240	30	>600	
		66186					20	100	400	30	>600	
		66475					89	35	1250	18	>1500	
		HD20,000					30			9		
		LD1,000							200		>325	
		X					18	85*	>350	30	>500	
		HD40,000										
2.5.14	Permealiner	M-1195	Staff Industries	1	4	7.2		85	400	34	510	92
		M-1105		1	4	6.5		30	275	28	520	110
		ISS-1		1	2	5.0	14	60	110	22	300	30
		ISS-2		1	2	7.5	18	120	160	12	400	30
2.5.15	Petromat		Philips	1	2	4.1			115	65		
2.5.16	Polyfelt		Advance	2	2	7.8	127		228	101		47
2.5.17	Poly-Filter	X	Carthage Mills	1	4	7.2		70	380	23		
		GB				6.6		40	200	23		
2.5.18	ProPex	II	Amoco Fabrics	1	4	6.5		30	275	28	520*	110
2.5.19	Reemay	2006	duPont	2	1	0.6	6		11		12	
		2011				0.7	7		14		31	
		2014				1.0	9		22		31	
		2016				1.3	10		31		46	
		2024				2.1	12		52		65	
		2033				2.9	16		70		96	
		2408				1.1	12		16		21	
		2416				1.5	14		22		28	
		2431				2.4	18		45		46	
		2441				2.9	20		56		58	
		2470				5.8	32		117		88	
2.5.20	Sontara	8000	duPont	2	5	1.2	16		25	40	35	
		8002				1.9	21		40	40	55	
2.5.21	Stabilenika	T-80	American Enka	2	5	2.3	20		64	55		29
		T-100				3.4	30		80	41		29
		T-140				4.3	30		129	42		30
2.5.22	Supac	5-P	Philips	1	2	5.3	50		125	80	300	73
2.5.23	Terrafix	300 NA	Erosion Control	5	5	14.7	137	50	200*	25	360	
		500 NA				20.6	177	70	200*	25	445	
		400 NR				16	160	120	120*		300	
		270R				8	118	100	150*		300	
		470R				11	160	120	200*		400	
		1000R				29	236	120	425*		800	
		1600R				47.2	236	120	700*		BMC	
		814B				22.1	236	120	350*		536	
		1002NS				32.5	453					
		370RS				14	157	120	90*		390	
		2415				3.7	18	50	105*		280	
2.5.24	Terram	500	ICI Fibres	5	3							
		700										
		1000										
		1500										
		2000										
		3000										
2.5.25	Typar	3401	duPont	1	1	4.0	15	85*	130	62	170	70
		3601		1	1	6.0	19	155*	225	63	263	75
		T063		5	5	7.5	15.5		180	68	265	54
2.5.26	Tyvek		duPont	5	1							

[a] Fiber type:
1. Polypropylene
2. Polyester
3. Nylon
4. Glass
5. Other or combined

[b] Process type:
1. Nonwoven, spun bonded
2. Nonwoven, needled, or mechanically bonded
3. Nonwoven, thermal, or melt bonded
4. Woven
5. Other, combined, or not known

[c] ASTM D 1910.
[d] ASTM D 1777.
[e] Corps of Engineers CW-02215.
[f] ASTM D 1682 (machine direction with dry fabric).
[g] ASTM D 1682 (machine direction with dry fabric).
[h] ASTM D 774, D 231, D 751.
[i] ASTM D 2263 (machine direction).
*Signifies a different test than above or test modified in company literature.
Many values have been averaged when a test range was given.

Table 2
Physical Properties of an Extruded
Polystyrene Foam Insulation Board

Property	Test Method	Value
Thermal Resistance measured on 25 mm thickness (m^2 °C/Watt) (R value at mean temp. of 24°C)	ASTM C518-70 C177-63	35 psi ....0.87 60 psi 0.87
Compressive strength, kPa (at yield or 5% deflection)	ASTM D1621-64	35 psi .....240 min. 60 psi .....410 min.
Water absorption (% by volume)	ASTM D2842	35 psi ....0.70 max. 60 psi ....0.70 max.

Board dimensions

Thickness, mm	Width, mm	Length, mm
Nominal	Nom.	Nom.
25.0	600	2400
40.0	600	2400
50.0	600	2400
75.0	600	2400

insulation boards must be staggered and the construction of the insulation workpads should be limited to the winter months due to practical, structural and thermal design considerations. The drainage structures, which are an important aspect of these insulated embankments, must be field-staked in the summer months and early fall before the construction begins (21).

Thermal conductivity "k" of most gravels range between 1.17-1.19 Btu/Ft. -hr. °F (2.9 - 3.3 w/m °K.), whereas the "k" values for the NPR-A sands in question may range between 1.4 - 1.6 Btu/Ft -hr. °F (2.4 - 2.8 w/m °K). This indicates that for thermal design shallower sand embankments will provide the same insulating value as a higher grand embankment (36). Then the question of embankment design in the NPR-A becomes one of bearing value rather than thermal.

b. Sulphur Foam Insulation

Sulphur in its pure elemental form is known to be a good insulator. Patents for the production of a "honey-combed" insulating sulphur material were obtained as early as 1919. Southwest Research Institute (SwRI) of Canada is studying ways of commercially producing "Sulfur-Foam". In 1971 Chevron Research Company acquired the rights to the foam technology and is still in the process of research and development of both the foam properties and production techniques. "'Sulfur-Foam'" (Fig. 22) is a solid, rigid, cellular material, possessing a low density, high strength, uniformity of product, and good insulating properties" (24). The physical properties of "Sulfur-Foam" with various densities is shown in Table 3. Field experiments of "Sulfur-Foam" with various densities is shown in Table 3. Field experiments of "Sulphur-Foam" took place near Fairbanks, Alaska in 1972, and later the same year it was also tested in Japan for foundation installations under a liquid petroleum gas (L.P.G.) cyrogenic storage tank. These field tests demonstrate that this product will effectively withstand heavy loads under very low temperature conditions. "Sulfur Foam" was again field tested in Canada on a section of the Dempster Highway 40 mi. (64 km) south of Inuvik, Northwest Territories in August 1974, and on a section of the Anderson Road near Calgary, Alberta during October and November of 1974 at temperatures around 25 °F (4 °C) (25). Present surveillance of these installations indicates satisfactory performance in all cases. Along with these tests a commercial portable field unit which operates at chill factor temperatures as low as -50 °F (46 °C) has

Mixing head of foamed, sufoam at cream stage

Cross-section of typical sufoam

FIG. 22

TABLE 3 Typical properties of sulphur foam of various densities. The ranges shown are achievable by changes in formulation.

		ASTM Method	Type I Density pcf (kg/m^3) 4.5(70)	6.5(100)	10(160)	20(320)	30(480)	Type II (1) 20(320)
Thermal Conductivity		D2326						
BTU-in/hr-ft^2-°F @ 86°F			0.24	0.25	0.28	0.34	0.44	0.34
kW/m°C @ 30°C (x 10^{-4})			3.5	3.6	4.0	4.9	6.3	4.9
Coefficient of Linear Expansion		D696						
°F^{-1} (x 10^{-5})					1.9	1.3	0.9	
°C^{-1} (x 10^{-5})					3.4	2.3	1.6	
Compressive Strength (2)	psi	D1621	20-30	30-45	50-90	150-200	250-320	80-100
	MPa		01.-0.2	0.2-0.3	0.3-0.6	1.0-1.4	1.7-2.2	0.6-0.7
Compressive Modulus (3)	psi	D1621			2000-3000		9000-12000	
	MPa				13.8-20.7		62.1-82.7	
Flexural Strength,	psi	D790	12-14		20-30	50-70	90-120	45
	MPa		0.1		0.1-0.2	0.3-0.5	0.6-0.8	0.3
Flexural Modulus (3)	psi	D790			3000-7000	~5000		
	MPa				20.7-48.3	~34.5		
Resilient Modulus (4)	psi				~16000	~36000		
	MPa				~110	~250		
Dynamic Loading (5)								
Cycles at 15	psi				$>10^6$			
1.0	MPa				$>6.9 \times 10^3$			
Water Vapor Permeability, perm-in		C355						
Core (no skin)			11	9	10	10		
One Skin contact			0.8	1.5	<1	0.5		
Water Absorption, Vol %		D2127	1.5		1-2	1-2	<1	
Closed Cells, % of Cell Content		D1940-62T	3		5-85	18-84	27-90	8
Freeze-Thaw Resistance (100 cycles)		C290-67	No crack	No crack	No crack	No crack	No crack	No crack

(1) Type II foam is a lower cost/lower performance material. (2) Measured parallel to foam rise, at maximum stress to 10% deformation.
(3) Very rough estimates. (4) Compressive stress/strain under repeated loading conditions (0.1 sec. loading at 20 applications/min.).
(5) Compressions of 1.3 sec. duration at 26 applications/min.

been built and field tested with satisfactory results. It is recommended that the foam insulation be installed during the winter months to avoid trapping summer heat thus arresting the degradation of permafrost during the summer periods. The elimination of stress relief cracking due to cooling of the hot foam is accomplished by lubricating the surface underneath the foam lessening the adhesion. Foam should have some cracks to accomodate those caused by subsequent small structural shifts of the encapsulated embankment (25). Experiments and research indicate that "...soil pH around the foams at Dempster Highway measured two years after the installation was never lower than the pH of surrounding native soil. "Sulfur-Foam's" low toxidity is indicated by the LD 50 of 5g/kg (rat) of the 100% (96 hr) survival rate in a fish bioassay with stickleback" (24).

"Sulfur-Foam" is prepared by various methods. First a chemically mofified sulphur concentrate is prepared, and mixed with elemental sulphur to make what is know as a "foam precursor." The molten precursor is mixed with a polyisocyanate foaming agent with a very small amount of surfactant to produce the foam. The operating temperatures of "Sulfur Foam" range from -200°F to 150°F (-128°C to 66°C). Tests indicate that this material takes 12 hours to set and can be used around the membrane encapusulated embankments as shown in Figure 21.

3. Chemical and Mineral Binders

Chemical binders to be used with the NPR-A soils are mainly for surface treatments and pavements over the embankment structures.

a. Asphaltic emulsions.

Asphaltic emulsions have been used to stabilize sands since the late 1930's (26). In regions of Alaska where climatic conditions are somewhat similar to that of the NPR-A (i.e. ... Hooper Bay, Kotzebue, Whales), emulsion pavements have been successfully tested and are presently in use.

Knowledge gained from actual field experiences and laboratory tests indicate that sands with sufficient silt-clay material respond well to emulsions. A trace of Portland cement is also required to improve the water-susceptibility of these mixtures. Cationic emulsions are preferred to anionic emulsions in sand

stabilization because of their rapid setting tendencies and superior bonding to siliceous aggregates, caused by strong attraction of the minute globules of asphalt in the emulsion to the surface of "electro-negative" sand particles. In the NPR-A the thickness design must consider not only the plastic deformation and fatigue cracking, but also the important factor of ambient temperatures. Through the years mix and thickness design requirements have been well established to preclude these distresses of the ETM (Emulsion-Treated-Mix) pavements. A typical mix for the NPR-A silty sands would have 1-2% Portland cement and a CSS-2 or CSS-1type of 6-15% emulsified asphalt within a cold sand mix (27, 28).

The lay-down of emulsified asphalt cold mixes can be accomplished with towed type or self-propelled base spreaders working in ambient temperatures of not less than 32°F (0°C). Cold mixes have been placed in lifts of 4 inches (10 cm) or more, but to facilitate compaction and curing processes, 2-3 in. (5-7.5 cm) compacted layers should be used and rolled as soon as possible. Under some traffic conditions raveling may occur. To prevent further damage to the surface, the loose material should be groomed off quickly followed by asphalt enrichment of the surface through a light fogging with an SS-emulsion. If the raveling is because of a tacky surface, light blotting with sand should alleviate the problem.

The advantages of cold mixes over hot mixes are economy, cleaner production, and safety. They can be used for base, surfacing, widening and overlay or as a leveling course and are adaptable to strengthening and upgrading of old thin pavements.

Research and field testing begun in the early 1960's continues on "Dust Palliatives" that consolidate the embankment surface silt into a flexible continuous. These are water insoluble and nonlifting; their thermal susceptibility to low temperatures has been proved adequate through experimental tracks in the Prudhoe Bay area (29).

b. Soil Cement

Throughout the world, soil cement has been used extensively in the developing countries of warm climates. A typical mix using the NPR-A silty sands would consist of 15-20% Portland cement with 10% water by weight. Although they have been successfully used in Alaska in areas such as Hooper Bay and Bethel, their use in cold climates have been somewhat limited, and 4-6 in. (10-15 cm.) runway pavements that could support loaded Hercules aircraft have been successfully constructed.

Soil cement is also used as a synthetic aggregate in areas similar to NPR-A where natural coarse aggregates like gravel are not available. Trial mixes of 8-16% Portland cement have been tested and found to be satisfactory as bases in embankment construction (30).

In the production of soil-cement mixtures for NPR-A conditions, it is important to remember that the sand aggregates should be chilled to near freezing temperatures before use in the mixes.

c. Sulphur Asphalts

To the best of this writer's knowledge, Bacon and Bencowitz were the first to patent the production of a sulphur asphalt emulsion binder system in 1936. The large increases in the price of asphalt and the growing sulphur inventories, particularly in Alberta, Canada, generated a renewed interest in sulphur in the early 1970's. Today six agencies are working independently to develop sulphur-asphalt (S/A) emulsions to be used as binders in pavement construction and to make this emulsion technology commercially available. These agencies are: Societe Nationale Elf - Aquitaine (S.N.E.A.); Gulf Canada Limited; S.E. Pronk of R.M. Hardy and Associates LTD; Calgary Shell Canada LTD; the U.S. Bureau of Mines; and Texas Transportation Institute (31).

Sulphur asphalt emulsion mixtures are transported, placed, and compacted just like hot mixes utilizing the conventional equipment and procedures,. The only modification is in the asphalt paving plant that produces the emlusified binder.

There are three major agencies involved in the research of the sulphur asphalt emulsions with different emulsion compositions. The first is Gulf Canada LTD and it uses a typical emulsion composition of 25-60 parts sulphur to 75-40 parts asphaltic cement with the emulsion temperatures at 250° - 309°F (121° - 154°C). Recent trial demonstrations were held in Holland, Ontario, and in Saudi Arabia.

The second major technology is being developed by Frank E. Pronk dealing with "Stabilized Sulfur" in asphlatic emulsions for pavement construction. A typical composition contains 60-70% asphalt, 3-40% sulphur and 0.001% siloxane polymer based on the weight of the asphalt cement with mixing temperatures at 266° - 293°F (130° - 145°C). Field trials of this emulsion have successfully taken place in Canada and in West Germany. In these trials typical pavement thicknesses were 7 in. (18 cm) placed in two lifts of 3.5 in. (9 cm).

S.N.E.A., the third of three major agencies that is involved in the production and research of S/A, was the first of the three groups to publish the details of their research in 1973. Their preferred mix ranges are 16.5-39% sulphur, with optimal manufacturing temperatures of 266° - 338° (130° - 170°C).

Several field demonstrations of the S.N.E.A. process have been performed in Europe, North America and the Middle East.

Investigations by Gulf Canada Ltd. concerning the low temperature properties of S/A emulsion mixes "...indicate that sulphur asphalts approach more closely to the ideal mix than conventional asphaltic concretes." (31). The most important quality of the sulphur asphalt emulsions is that the addition of sulphur permits the substitution of low grade aggregates, such as the silty sands of the NPR-A, instead of the conventional high quality gravel without losing any of the qualities of the conventional mixes. Other advantages are the reduced use of asphalt cement, potential cost, energy savings, and greater strength.

Shell's "Thermopave" process with its Sulphur-Asphalt-Mix-Paver eliminates the need for mixing plant modifications and prevents the risk of toxic fume generation. This paver is ideally suited for the handling of sulphur concrete and similar mixes which are normally prone to quick cooling and the crusting that occurs especially in the cold regions (32).

The suitability of sulphur/asphalt emulsions as binders for pavements have been field tested and accepted by the three major agencies (31,32).

B. Lightweight Aggregate (LWA) Products

Synthetic aggregates have been used successfully in embankments and pavements since the 1930's. Lightweight aggregates which are in essence synthetic aggregates again came into focus when construc tion in the Arctic became necessary. This discussion covers two main lightweight aggregate products.

1. Expanded Polystyrene Concrete

Since the 1950's, laboratory and field investigations have been conducted to determine the strength, insulating and durability properties, behavior under repeated loads, and the effect of

expanded polystyrene concrete subbase on modulus of subgrade reaction. Expanded polystyrene concrete is a form of lightweight concrete which contains expanded polystyrene beads, water, sand, cement, and admixtures. By changing the expanded polystyrene bead content of the mix, its density may be varied from approximately 34-48 pcf (545 -769 kg/m^3). The physical properties of a 28-day moist-cured expanded polystyrene concrete are listed below (33):

Strength Properties

Flexural Strength	120-150 psi (827-1034 KPa)
Compressive Strength	325-550 psi (2.2-3. MPa)
Modulus of Elasticity	
In Flexure	100,000-160,000 psi (689-1,103 MPa)
In Compression	135,000-205,000 psi (931-1,413 MPa)
Dynamic Modulus of Elasticity	300,000-530,000 psi (2.3-3.7 GPa)

Durability and Insulating Properties

These properties are determined from field and laboratory tests.

Drying Shrinkage 73° F (22.8° C), 50% R.H.	2,450-2,880 millionths (after one year)
Wetting-Expansion 73° F (22.8° C), 100% R.H.	560-750,000 millionths (after one year)
Permeability	negligible
Absorption	7-11% by weight after 1 day.
	10-19% by weight after 28 days.
Freeze-Thaw Resistance	4-11% reduction in the dynamic modulus of elasticity and 25% reduction in flexural strength after 225 freeze-thaw cycles.

Thermal Conductivity	0.09 Btu/hr. ft. °F (0.16 w/m.°K)
Specific Heat	1.26 Btu/lb. °F 0.30 (J/Kg.°K)

As a comparison, granular base course materials (subbase) have thermal conductivities ranging from 1.7-1.9 Btu/hr. ft.°F (±2.9 3.3 W/m.K°) and specific heats of about 0.1 Btu/lb.°F (419 J/kg. K°). Expanded polystrene concrete has a modulus of elasticity of about 150,000 psi (1,034 MPa), whereas the granular subbase material has a modulus of elasticity of only 30,000 psi (207 MPa). An analysis for both rigid and flexible pavements, based on the Burmiester theory for a layered system and using the modulus of elasticities mentioned above, showed that the effect of an expanded polystyrene subbase on pavement stresses, compared to the granular subbase, was 3 in. (7.6 cm.) of granular subbase to 1 in. (2.5 cm.) of expanded polystyrene concrete subbase. Similar ratios were observed in designs to effectively reduce or eliminate frost penetration into subgrades under rigid or flexible pavements.

Laboratory and field test results further indicate that "... expanded polystyrene concrete subbases effectively reduce or totally eliminate frost penetration into subgrades under rigid and flexible pavements... A 1 in. (2.5cm) expanded polystyrene concrete subbase is as effective as 3 in. (7.6cm) granular subbase... The reduced pavement deflections and stresses thereby increase pavement loadcarrying capacity... Also, the effect of an expanded polystyrene concrete subbase on pavement stresses is similar to that of a relatively thicker granular subbase." (33).

2. Silicate Glass Aggregate Asphaltic Concrete

The second lightweight expanded aggregate that will be considered is a silicate glass aggregate (36). A patented silicate aggregate is heated to about 1000°F (540°C), expanded, and its volume is increased 10 to 25 times the original, resulting in a material with densities as low as 2 pcf. (32 kg/m^3).

Physical properties of this amorphous (shapeless) expanded silicate aggregate are listed below:

Color	Off-White
Loose Bulk Density	3.34 lbs/cu.ft. (53 kg/m^3)
K Factor (Btu/hr/ sq. ft. °F/in. at 75°F) (kW/m °C @ 24° C x 10^{-4})	0.28 (4.0)

Softening Temperature	1100°F (593°C)
Particle Size	#8-#10 mesh to 0.5 in. size
Compressive Strength	50-135 psi (3.65-9.9 kg/cm^2)
Odor	None
Flash Point	None-Flammable (Totally inorganic)
Freeze-Thaw Frozen at 0°F (32°C), thawed at 60°F (15.6°C)	More than 50 cycles

Physical Properties of Lightweight Silicate Aggregate Mixed with Modified Thermoplastic Asphalt Binder:

Composition	Amorphous expanded glass lightweight aggregate and thermoplastic binder.
Hygroscopicity	None
Capillarity	None
Curing Time	None
Acid Resistance	Impervious to common acids and salts.
Thermal Conductivity Btu/hr/FT^2-°F/in @ 75°F (Water-saturated) (kW/m°C @ 24°C x 10^{-4})	0.32 ("K Factor") (4.6)
Compressive Strength (wet)	160-175 psi (11.2 - 12.3 kg/cm^2)
Percent Strain at Failure or 10% Strain Criteria	3.7%
Marshall Stability	+900 lbs.
California Bearing Ratio	10.1-10.7%
Flexural Strength	120 psi (8.4 $kg.cm^2$)

Freeze-Thaw Resistance 0°F-60°F (-17.8 to 15.6°C)	More than 50 freeze thaw cycles.
Water Saturation Effects	No damage.

Amorphous expanded silicate glass aggregate and the asphalt thermoplastic binder can be combined at the job site with standard mobile portable equipment composed of a portable expander and mixer. On small jobs, the composition can be mixed and compacted by hand using regular garden tools. For embankments, standard mobile asphalt equipment or hand-pushed lawn rollers are used in compacting the mix. Larger jobs require equipment that consist of a small pug mill, a laydown machine for asphaltic pavements, expanders, conveying equipment and larger rollers. The mix can be laid directly on the frozen tundra, or on an inch of sand after the snow has been removed. The laydown rates are the same as an asphaltic pavement and the mix can be compacted immediately by a mobile asphalt roller or similar equipment mentioned above, without the need of a sealant to prevent moisture or water penetration. The mix can be poured in monolithic layers without joints or moisture barriers and will not deform or crack under specified design loads or when frozen. Although no granular topping is required in most embankment situations, in the case of roads with heavy traffic a 6 in. (15cm.) granular mix surfacing may be necessary, which is trafficable as soon as it is laid and compacted. When compared with gravel, the construction time reductions are more than 3 times. It outperforms styrofoam or urethane foam insulations under extremely wet freeze-thaw conditions and can be applied in weather conditions encountered in the Arctic and NPR-A. A 2.5 in. (6.3 cm.) of this composition is equal to about 6 ft. (183 cm.) of gravel. This amount is based on the "K" factors of gravel at 13.0 and the mix at a high value of 0.4 (33). Field and laboratory experiments show that, in areas similar to NPR-A, this mix is an economical alternate to gravel in the construction of roadway embankments, pipeline support pads, airfield, drilling pad, building foundations, and other similar embankments (33, 34, 35).

C. Mats

The introduction of the hydrocarbon industry into Arctic Alaska, especially NPR-A, initiated a new phase for its exploration and production of hydrocarbons. To improve and/or establish the auxiliary systems for hydrocarbon exploration and production, such as transportation and maintenance, among the important factors are to be considered are the techniques and surfacing materials needed to minimize the deterioration and maximize the bearing capacity of embankments.

This section covers the use of prefabricated surfacing materials referred to as mats, utilized for the above improvements. A survey of prefabricated surfacing materials indicate that a good selection is presently available as categorized below:

1. <u>Aluminum Mats and Planking</u>

   Aluminum mats and planking have been quite popular since the 1950s. The products in demand consist mostly of extrusions that are less expensive than the bonded systems. Extruded aluminum planking systems usually consist of interlocking double-faced panels that are 2 ft. (61 cm.) wide by 4 ft. (122 cm) to 12 ft. (377 cm.) long by 1.5 in. (3.8 cm.) thick, Fig. 23, 24. These panels usually have a bonded nonskid wearing surface, and interlock on their longer sides to form a variable width runway, roadway, or other type of surface. Actual experience and tests indicate that in the NPR-A region aluminum planking will be suitable for C-130 runways as well as roads that carry vehicular traffic up to 70-kip single-tandem gear loads (19,37). The planking is anchored on a two layers of 1.5 in. (3.8 cm) of 60 psi (4.2 kg/cm^2) styrofoam or equivalent insulation panels. These panels are placed on 20% CBR subgrade and a sandfill embankment compacted with eight coverages of 60 psi pneumatic-tired, 50 ton roller.

   The mats used for surfacing are also extruded aluminum with a honeycomb structure. They are usually 2 ft. (61 cm.) wide and anywhere from 4 ft. (122 cm.) to 12 ft. (366 cm.) long by 1.5 in. (3.8 cm.) thick. Standard panels usually come with a dark green nonskid bearing surface, whereas matting does not. Tests and theoretical calculations on solar radiation absorption indicate solar energy absorbed by the aluminum panels and mattings can be reduced up to 50% by a white wearing surface (39).

2. <u>Fiberglass and Plastic Matting</u>

   a. The recent entries to the prefabricated, portable surfacing systems (PPSS) are the fiberglass reinforced plastic mattings. These mats are laminates of resin-impregnated parallel glass fibers cured at high temperatures and pressures, where the good strength of the laminating process combined with a waffle-like pattern results in a lightweight 1.5 lbs./ft.^{3} (24kg./m^3), tough, reusable surfacing material with good load-spreading properties, durability and portability. These panels are molded into a waffle configuration with an overall thickness of 0.63 in. (1.6 cm.). They have a nonskid

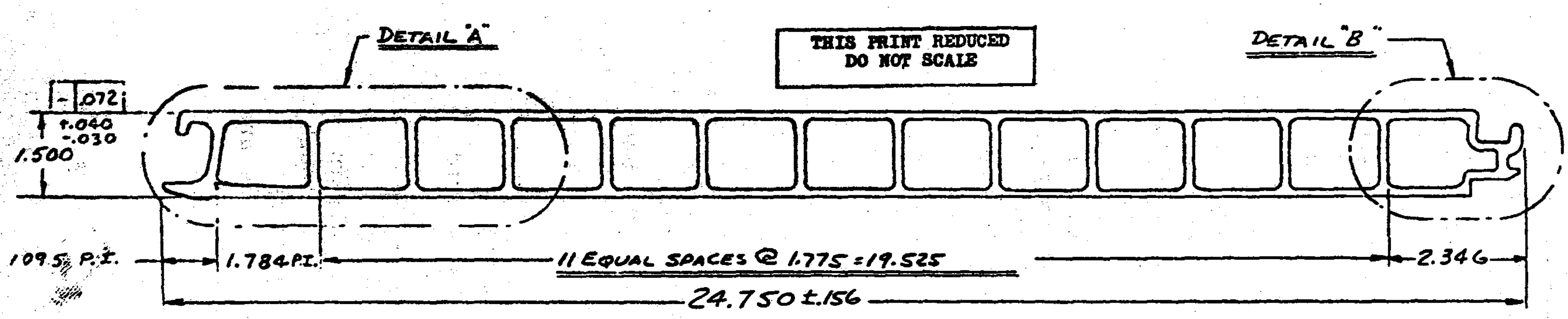


FIG. 23

FIG. 24 Placing XM19 landing mat over insulation

material bonded to the top surface and loop holds on the sides for connecting one panel to another or attaching edge stiffeners and anchor plates. To attach edge stiffeners or for joining panels, plastic nut plate strips are used in conjunction with bolts and washers. Their operating temperatures range from 130°F to -130°F (54°C to -90°C). They cannot be used under vehicles with tracks, such as dozers, etc. and can be repaired readily by bolting or epoxying on patches (Fig. 25). Each of the panels weigh 890 lbs. (403 kg.). They can be used as runway surfacing, on trackways/broadways, Fig. 26, 27, helicopter pads, (Fig. 28), vehicle parking and storage pads, drilling pad surfacings, ship-to-shore trackways, watercourse crossings (Fig. 29), and similar surfacings and are completely portable and reusable.

The load-bearing capabilities of this fiberglass-reinforced plastic mat ranges from supporting a moving, fully loaded five-ton truck over 2% CBR subgrade (Fig. 26), to a fully loaded CH-53 helicopter grossing 38,000 lbs (17,273 kg.) on a 100 ft.x 100 ft. (32.8 m. x 32.8 m.) mat on dry silty sand with 10% CBR, (Fig. 28). The mat used under a truck was 2 feet wider than the outside edges of the wheels of the truck to compensate for mat buckling, (Fig. 26) (38).

b. The other plastic mattings on the market are extrusions of the new high-strength polyethelenes that are pulled after the weight-reducing holes are punched. This pulling process implants a pretensilized "memory" into the extrusion while it is still warm. These products are recently commercialized and have not been tested in the Arctic regions. However, laboratory and field tests in warmer climates indicate that that they are usable in Arctic regions similar to NPRA, provided that they are placed on surfaces insulated with high-strength materials that would compensate for their excessive heat-transfer qualities, (Fig. 30, 31), (51).

3. <u>Steel Mats</u>

Steel mats, employed before aluminum planks and mats were commercially available are no longer used.

4. <u>Treated and Fiberglass-Coated Plywood</u>

The introduction of high-strength plastics and fiberglass coatings into the materials industry has revitalized the use of plywood as a construction material. Coated plywood is used favorably not only as a stiffener, but also as an insulator comparable to synthetic extruded polystyrene insulation (39).

REPAIR PROCEDURE

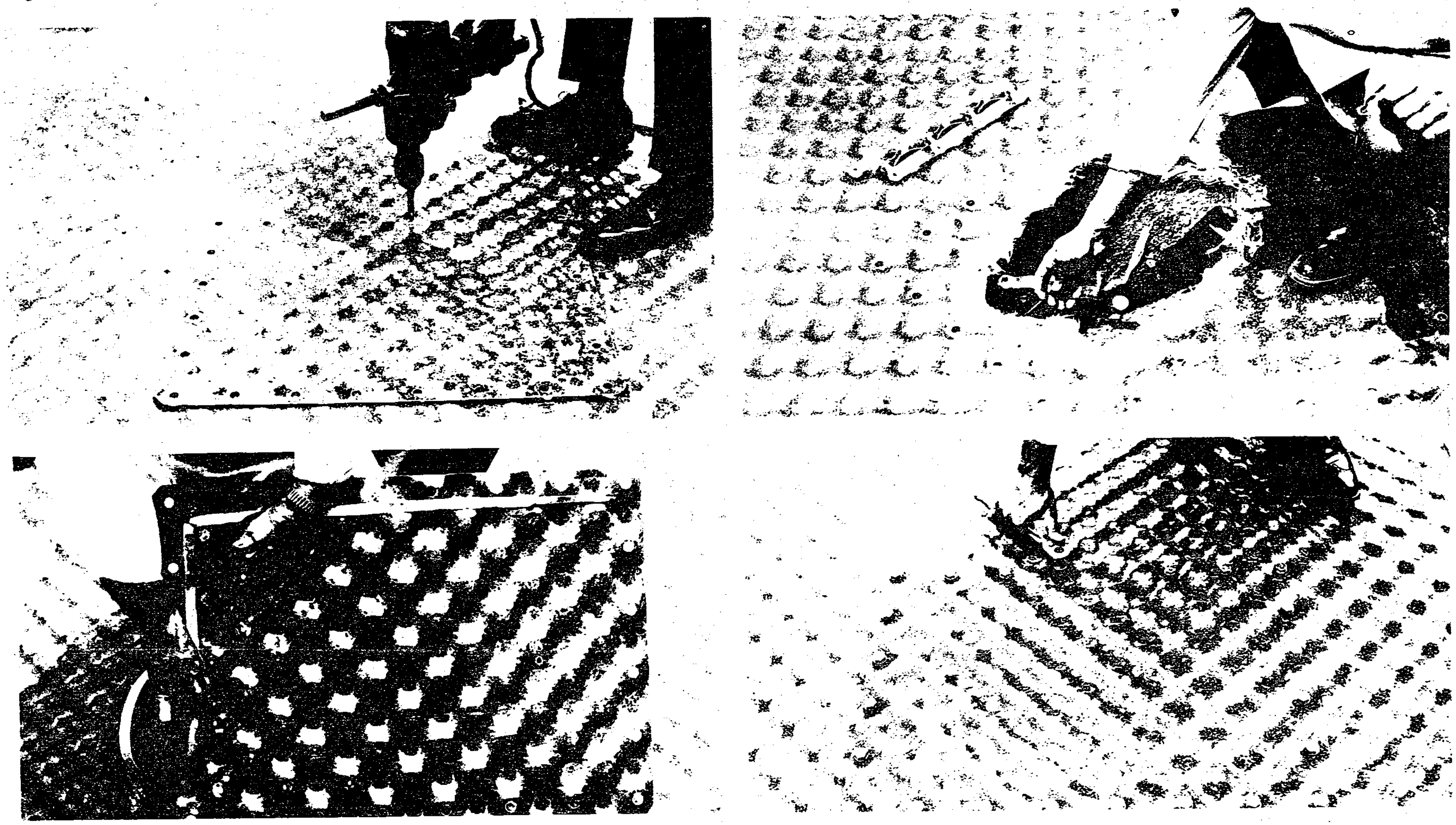


FIG. 25

TRACKWAY / ROADWAYS

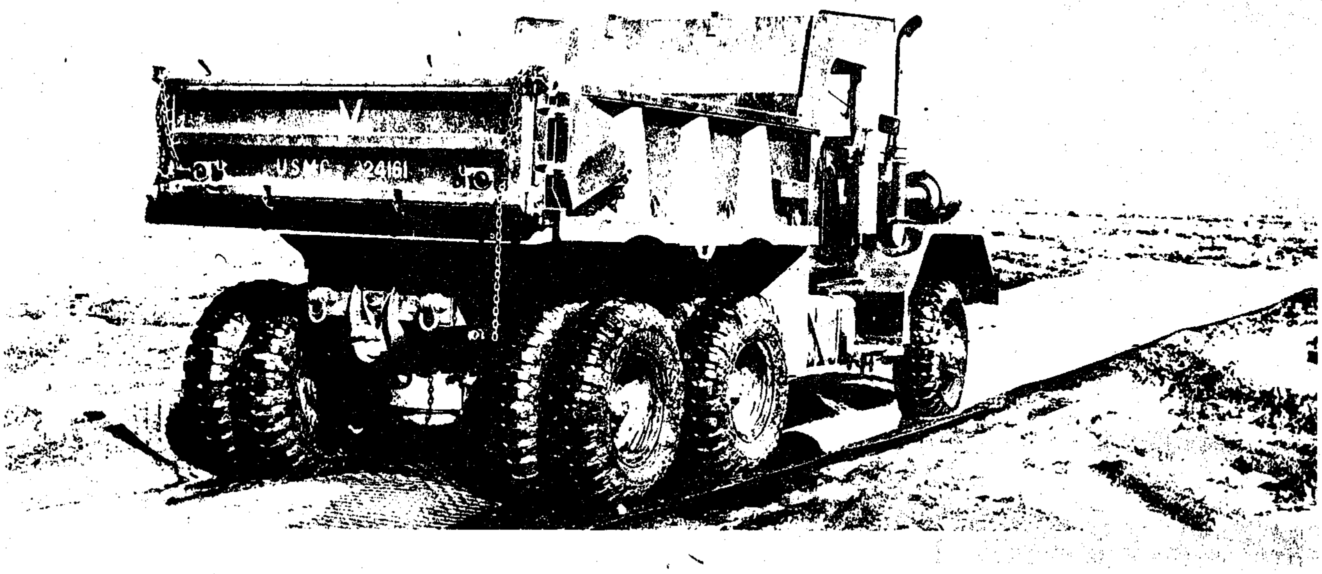


FIG. 26

ROADWAYS

FIG. 27

LANDING PADS

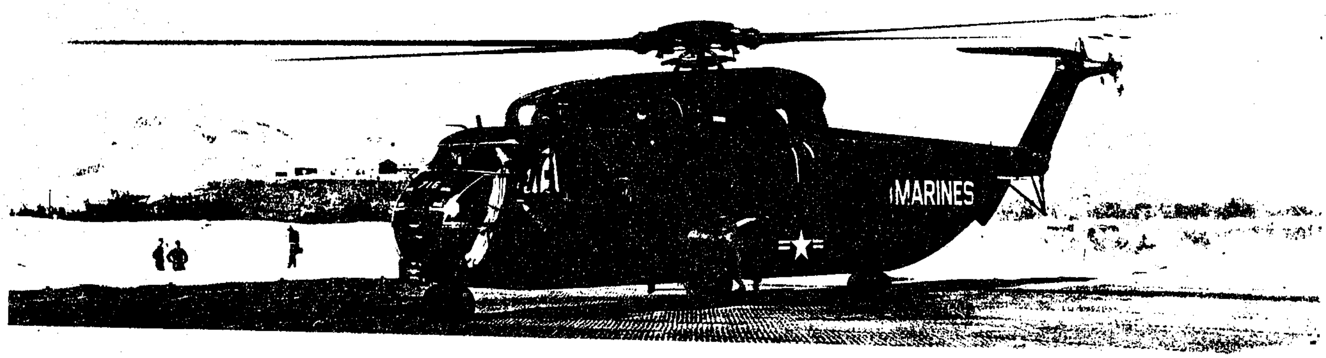


FIG. 28

RIVER CROSSING

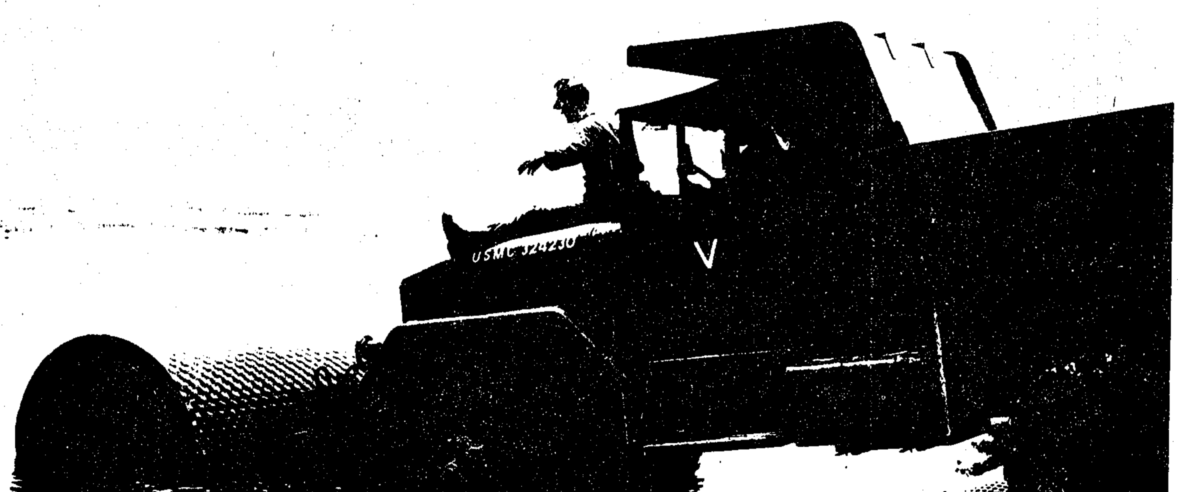


FIG. 29

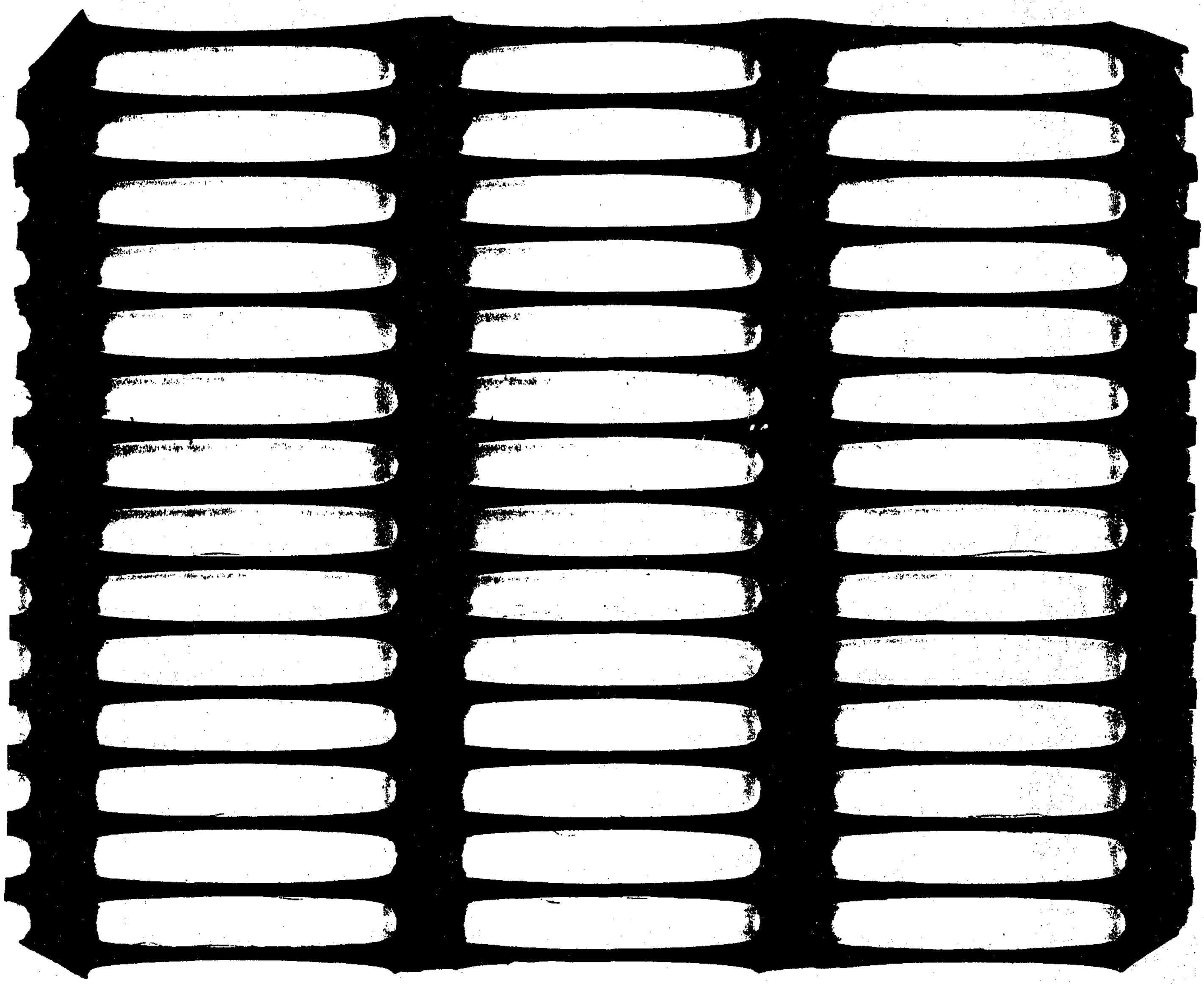


FIG. 30 - Tensar SR-1
Soil Reinforcement Grid

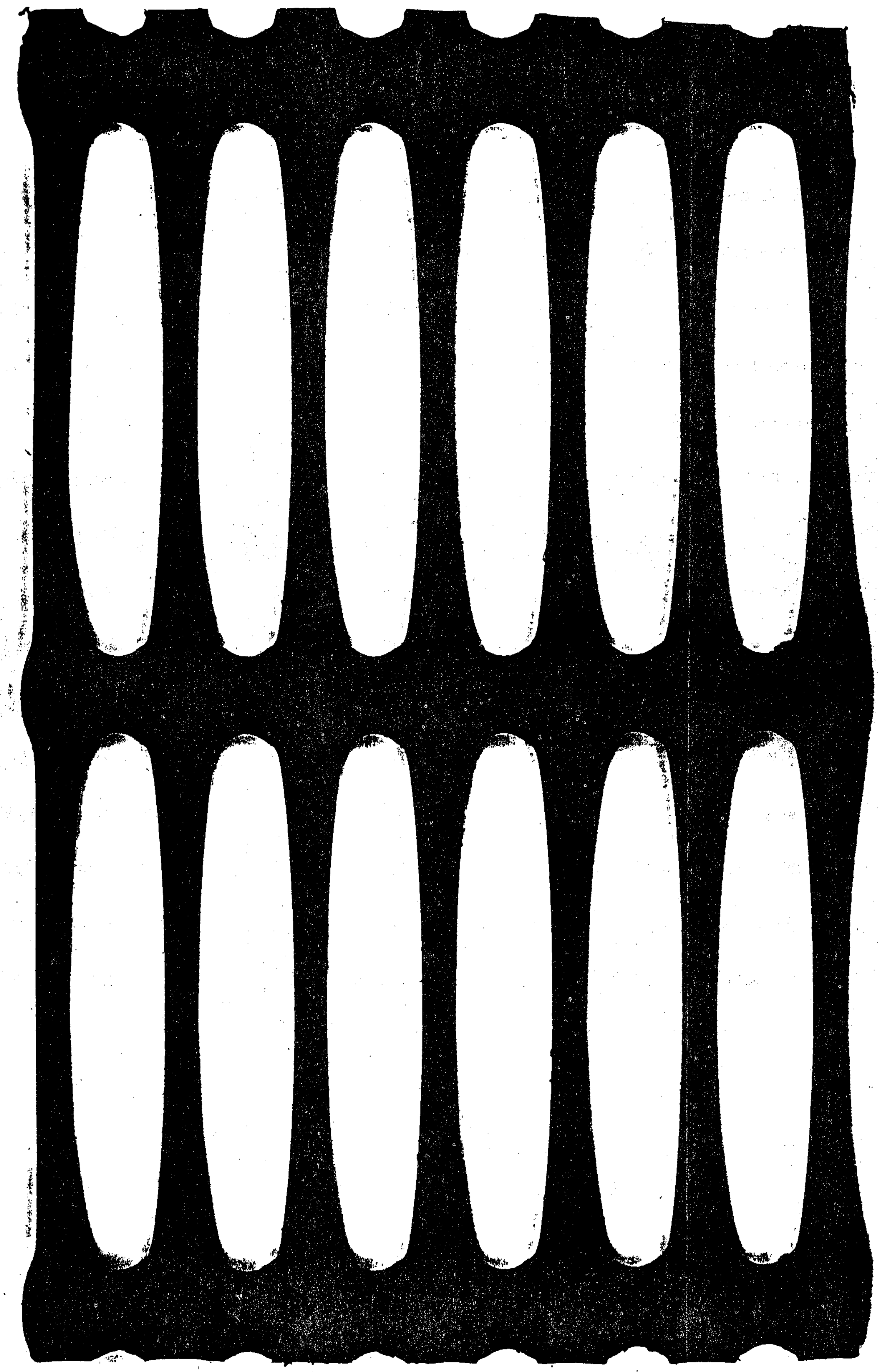


FIG. 31 - Tensar SR-2 Soil Reinforcement Grid

D. Winter Roads And Paths

Personal experience, literature research, and interviews with professionals in Canada and Alaska who have first-hand experience in design construction and maintenance of winter roads, indicate that there are ten basic types of winter roads. Any trafficable road or path constructed out of snow or ice, a mixture of soil, or just pure snow or ice that is functional only during the winter, is called a winter road. The three main categories are: winter trails; snow roads and paths; and ice roads, bridges and aircraft runways.

1. Winter Trails

Winter trails have two broad categories.

a. Temporary winter trails constructed by a single path of tracked or wheeled equipment, such as a bulldozer or grader, to gain access for one winter season only.

b. Perennial winter trails designed and constructed to be used over several winter seasons.

2. Snow Roads and Paths

Snow roads have been used in the cold regions for many years, as arteries in transportation and construction facilities preventing the environment from being permanently damaged. North America logging operations have been using them since the turn of the century. They have been used in Arctic regions of Alaska since 1946, first in the NPR-A and then in the Prudhoe Bay area oil exploration programs. They were also used in Greenland during the 1950's in the installation of the DEW-Line stations. In 1976, D. E. Keyes' paper described the use of snow and ice for oil pipeline construction pads, roads, and runways (46). E.N. Fisher developed a concept of ice aggregates and initiated a technological breakthrough in 1977 (47).

Preconstruction planning for the snow roads and paths must consider route selection, right-of-way, and environmental protection factors. Construction techniques involve the use of crawler-tractors, wheeled equipment with blades, or any other low-ground pressure vehicles after sufficient frost had penetrated the ground. The use of snow fences to collect drifting snow along the snow road route or path is an important construction technique, (Fig. 32), (44, 51). Compacting snow on the road or path alignment and collecting new snow in the depressions is also a good technique. There are four types of snow roads.

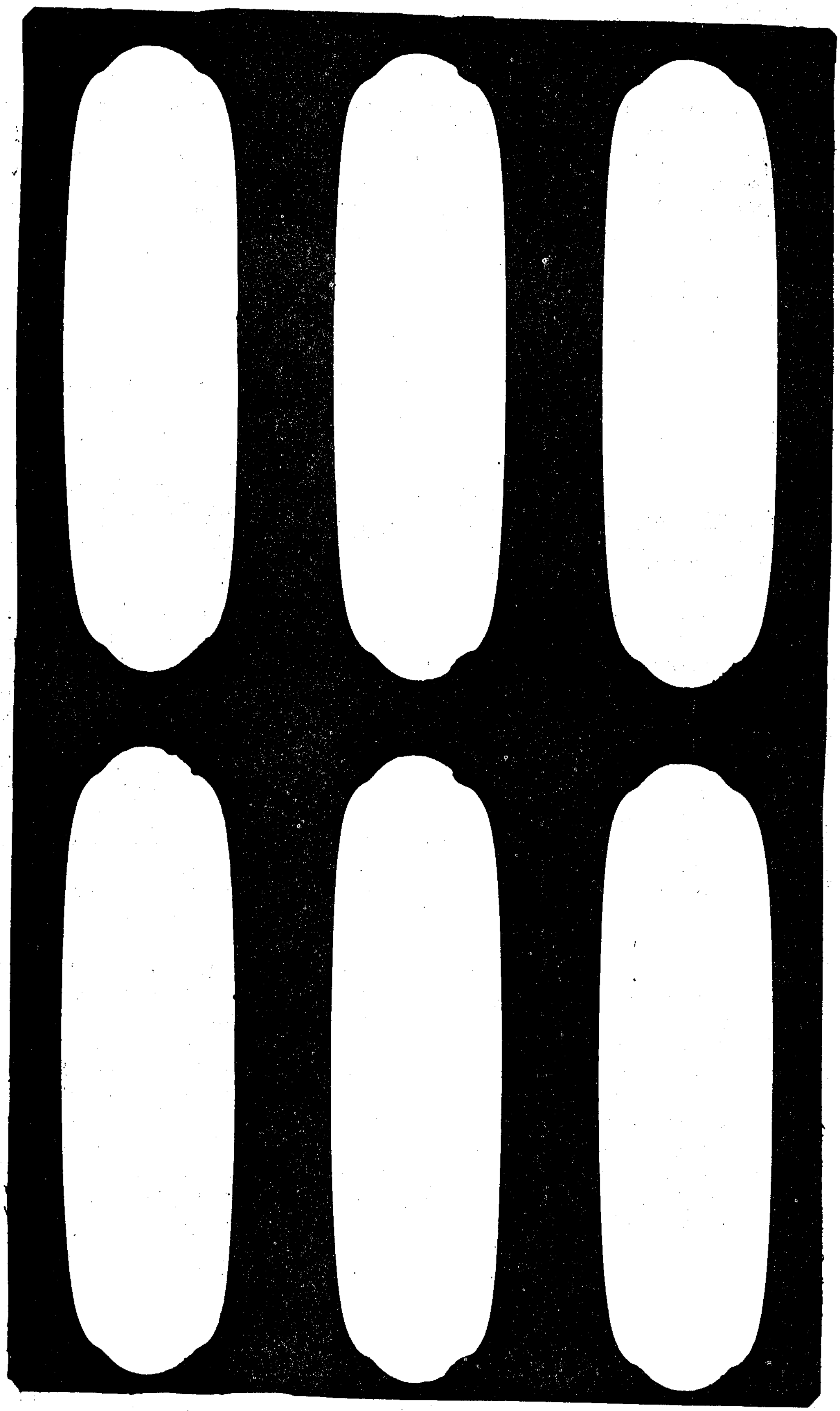


FIG. 32 - Tensar Snowfencing

a. Compacted Snow Roads

Compacted snow roads use large rollers at least 8 ft. (2.4m) in diameter, 4 ft. (1.2 m) in width, and weigh 10,000 lbs. (4500 kg.) and operate at speeds of 2-6 mph (3-9 km/hr.) to compact the snow (43, 44, 48). Compaction rollers with 13 pneumatic-tires are more effective after the snow receives its initial compaction and after the crystals are allowed to sinter and cement below -20°F and above -50°F (-29°C and -46°C) (46). Compacted density of the snow should be near or greater than 34 pcf. (544 kg./m^3) with a rammsonde hardness index of 450 after 24 hours or more of age-hardening (43).

b. Processed Snow Roads

Processed snow roads are similar to compacted snow roads, differing only in snow agitation and the crushing of the particles before compaction.

c. Ice-Caped Roads

Ice-caped snow roads are constructed in the same manner as the compacted snow roads or processed snow roads. At the end of snow embankment construction, water is sprayed on the snow surface to obtain greater stability by creating a minimum 1 in. (2.5 cm.) ice cap.

d. Artificial Snow Roads

Artificial snow roads are constructed with snow manufactured at the water source or on the alignment, with an in-place density of 25 pcf (400 kg/m^3). The excess free water around the artificial snow crystals cause the road embankment to freeze as a porous but rigid mass and be able to support traffic without compaction or leveling.

3. Ice Roads and Bridges

There are four types of ice roads and bridges utilized in the cold regions.

a. Solid Ice Roads

Solid ice roads are built by water ponding directly on the ground at a rate that does not result over 2 in. (5 cm.) depth. Ice should be built up to a minimum of 2 in. (5 cm.) thickness and sprayed water should be contained and not allowed to run to one side of the road, which may cause a thinner layer on the other side.

b. Aggregate Ice Roads

Aggregate ice roads are built out of crushed ice aggregates hauled on to the alignment. The ice aggregate particles should not be larger than 2 in. (5 cm.) and gradations should indicate that most of the voids in the embankment are filled. Experiments in the Arctic utilizing a small tiller, indicate that the construction of a roadway 24 ft. (7.3 m.) with an average embankment thickness of 1 ft. (30 cm) uses about 5900 C.Y./mi. (2800 m^3/km.) of ice-aggregate, and rates of 0.6 mi./day (1 km./day) are obtainable. These roads can be built with side slopes of 1.1, and the road surface may be finished by 1 in. (2.5 cm.) of water (43, 45, 47).

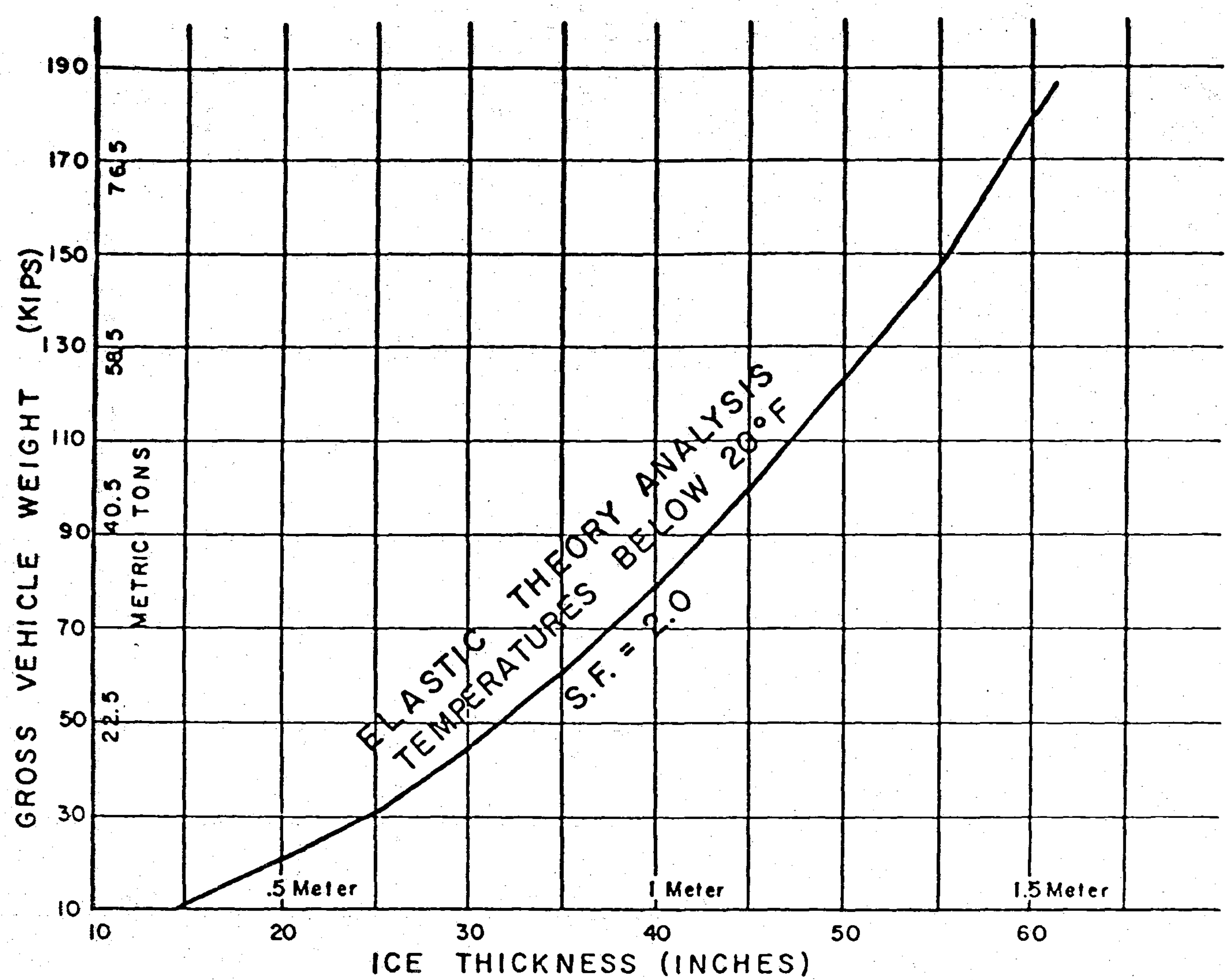
c. Roads on Ice

Roads on ice are ideally built on the surface of frozen lakes or rivers that have 10 to 12 in. (25-30 cm.) of ice thicknesses. Pressure ridges and leads that form on the ice in the same place every year are dangerous for travel, and construction timber ramps should be used when crossing them is absolutely necessary.

d. Ice Bridges and Aircraft Runways

Ice bridges and aircraft runways are constructed by flooding the ice surface to obtain a thick sheet of ice rather than relying on the natural ice growth and thickening at the bottom of the ice sheet, as is the case with roads on ice. A minimum thickness of about 3 in. (8 cm.) of clear, solid ice is required if the ice is not broken up,; if it is due to wind action etc., a minimum of 12 in. (30 cm.) thickness is required (40, 42, 46). Flooding ice and snow in place forms white ice, with 50% the strength of clear ice, a factor which should be considered seriously in the construction of white ice structures, and the thickness of the white ice layers should be at least twice the thickness of the clear ice layers as shown in (Fig. 33), (46). Embedding corduroy reinforcements in the ice embankment and gives more flexural strength. Clearing the snow 75-100 ft (25-30 m.) on either side of the ice bridge or the runway facilitates ice formation.

Operation and maintenance of winter roads vary with the type of road under consideration. In permafrost area winter trails only balloon tired or tracked vehicles should be used and, the trails should maintained by graders of light tracks. Snow roads can take all types of



FRESHWATER ICE DESIGN LOADING

(CLEAR ICE)

FIG. 33

traffic with speeds up to 50 mph (80 km/hr). Sanding or scarifying may be necessary at the curves or on grades where glare ice have been formed. Ice roads require minimum maintenance among all the winter roads. Recent works by D.E. Nevel (50) have provided further insight into the design of ice bridges, runways and roads on ice. In designing these ice structures, the maximum tensile stress in an infinite sheet of ice carrying a load of known magnitude and geometry can be calculated. The ice thickness-tensile stress relationship when the load and ice mechanical properties are held constant is:

$$h \sigma_t^{0.60} = C_c$$

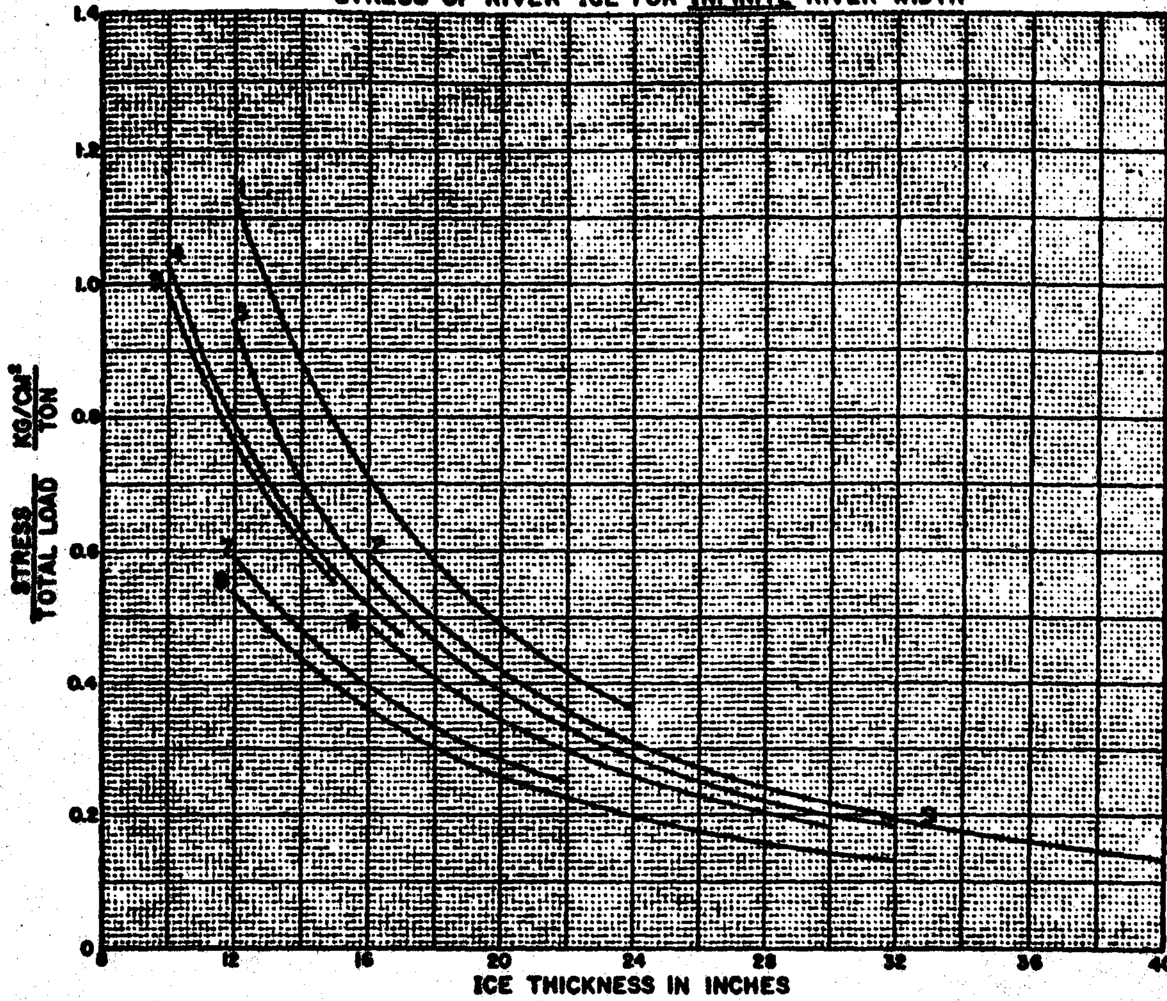
In this formula, h is the ice thickness in inches, and σ_t is the maximum tensile stress at the bottom of the ice sheet in psi. C_c is a constant that varies with the ice mechanical properties and the changes in load, and that can be calculated, allowing the "bearing capacity" of a floating ice sheet to be described in terms of maximum tensile stress in the ice, (Fig. 34). For some fresh-water clear ice, a tensile stress of 140 psi (10 kg/cm^2) is allowable provided the load is moving faster than 10-15 mph (16-24 km/hr.) and the traffic is not heavy (41). Golds' formula, $P=Ah^2$, where P = safe load in lbs., h = ice thickness in., A = a constant approximately 50 (P in kg., h in cm., A = 3.52) gives maximum loads on ice (49). Due to the waves generated by traffic on ice roads and bridges, speed limits below 20 mph. (32 km/hr) should be observed and on ice less than 30 in. (75 cm.) thick, traffic speeds should be less than 10 mph. (16 km/hr.) (43). Whenever the ambient temperatures are above 40°F (4°C), all vehicle and aircraft operations on these structures must cease.

E. Quarries

Available geologic and topographic maps, area photographs, literature, and the bedrock formation discussed in the "area" section of this paper indicate that quarrying operations are possible in the vicinity of Colville River and west of it in the Arctic Foothills Region of the NPR-A. Under normal climatic and topographic conditions, the feasability of quarrying in areas such as the Arctic Foothills Region of the NPR-A may be questioned; but in areas where gravel is not available, quarrying appears attractive. The geologic formations mentioned under the Geophysical Section of this paper indicate the availability of shales, chert, and limestones in this area. These type of rocks, depending on their soundness and hardness, can be used as subbases and surfacing materials for all types of embankments. The available data on quarrying in these regions of NPR-A is limited if not sketchy and test projects should be considered seriously.

FIG. 34

STRESS OF RIVER ICE FOR INFINITE RIVER WIDTH



		Total weight (tons)
1)	PCM113 or PCM577	11.5
2)	MS	21.1
	MS with commo van (AN/MRC-69	28.2
	SP M109 how	26.2
	20-ton crane	23.5
3)	M51 5-ton dump truck with winch-loaded	22.0
4)	M51 5-ton dump truck with winch-unloaded	11.3
5)	M52 5-ton tractor with winch	9.5
6)	M51 5-ton dump truck with winch-loaded and 3.5-ton bolster trailer-loaded	26.2
7)	M52 5-ton tractor with winch and M172 A1 25-ton low bed semi-trailer-unloaded	16.9
8)	M52 5-ton trailer with winch and M172 A1 25-ton low bed semi-trailer-unloaded	42.5
9)	M48 tank	49.0

Load/ice thickness/tensile stress relationship for a number of military vehicles.

F. Piles

Volumes of literature are available on pile foundation experiences in the Arctic regions where permafrost and seasonal frost dominate. The kind of pile chosen depends upon the foundation temperatures and materials, permafrost and seasonal frost zones, active layer thicknesses, loads to be carried, the seasonal temperatures and the accessibility of the area in NPR-A. Choice of materials are timber, plastic, paper and metal, coated or not coated. In the permafrost regions of the Arctic, drilled, slurried and frozen-in-place piles are common. Piles may be refrigerated using the various refrigeration systems available, their diameters and lengths varying with the factors mentioned above.

IV. ECONOMIC REVIEW OF THE ALTERNATES

The economic viability of the alternate materials presented is best expressed through a comparison of the costs of gravel embankments (if available) and the alternates that do not use gravel. The nonavailability of specific cost figures in NPR-A makes an economic analysis through assumed figures meaningless. The following is a review of the available costs of materials used in each alternate design[1].

A. Sands and Silts with Synthetic Fabrics and Membranes, Insulating Materials, Chemical and Mineral Binders.

Research indicates that the cost of the synthetic fabrics is anywhere from \$0.50 - \$1.50 square yard in the Anchorage area, varying with the different types of fabrics and quantities purchased. Fabrics treated with asphalt cements are available in the upper range of costs mentioned above. The Anchorage costs of insulation materials, such as expended polystyrene foam insulation boards, range between \$0.35 - \$0.70/ board foot. The cost of these products depends upon the quantities, different densities, and coatings. Fig. 35 shows cost reductions when insulating boards are used in embankments (21).

The costs of sulphur foam insulation vary with density and quality of the foam.

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[1]Contacts with Max Brewer of the Anchorage USGS revealed that no specific costs were available at this time for any of the hydrocarbon exploration facilities or tests conducted throughout the years in the NPRA. A cost figure of \$1.00 -\$100.00 pcy of gravel was stated by the USGS in NPRA.

When the Anchorage price of sulphur is around \$120/ton, the Anchorage in-place price of a 40 psi (2.1 kg/cm^2) and 6.5 PCF (104 $kg./m^3$) material would be around \$0.30 - \$0.45/ board foot. In the Alaskan Arctic regions, it is estimated that the costs of in-place sulphur foam would be 10 - 15% above the expanded polystyrene foam boards.

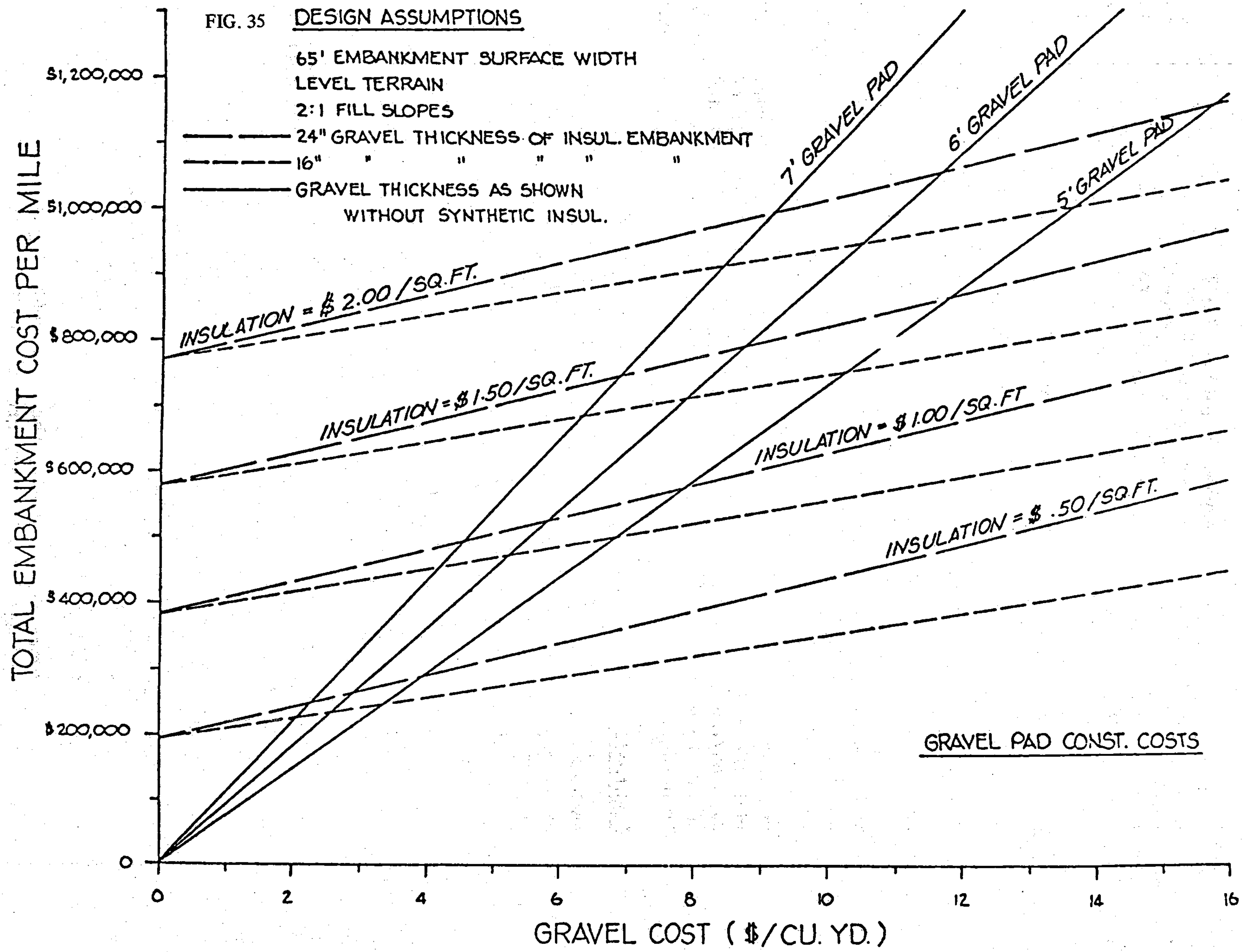

FIG. 35
DESIGN ASSUMPTIONS
65' EMBANKMENT SURFACE WIDTH
LEVEL TERRAIN
2:1 FILL SLOPES
24" GRAVEL THICKNESS OF INSUL. EMBANKMENT
16" " " " " "
GRAVEL THICKNESS AS SHOWN
WITHOUT SYNTHETIC INSUL.
7' GRAVEL PAD
6' GRAVEL PAD
5' GRAVEL PAD
INSULATION = $ 2.00 / SQ. FT.
INSULATION = $1.50 / SQ. FT.
INSULATION = $1.00 / SQ. FT
INSULATION = $ .50 / SQ. FT.
TOTAL EMBANKMENT COST PER MILE
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
0
0
2
4
6
8
10
12
14
16
GRAVEL COST ($/CU. YD.)
GRAVEL PAD CONST. COSTS

Chemical binders, such as asphaltic emulsions, mineral cements, and sulphur-asphalt emulsions are obtainable in the Anchorage area. Costs of asphaltic emulsions in Anchorage range from $195.00-$210.00 /ton. (240 gal./ ton). Cement costs in Anchorage are:

Type 1 - 2

SACKS	BULK
$6.00 - $6.20 / 94 lb. sack	$114.00 - $118.00 / ton
Type 3	
$6.30 - $6.60 / 94 lb. sack	$120.00 - $125.00 / ton

There is an additional charge of $0.41 for palletizing. The additives for permafrost, aeration etc. are extra and Anchorage costs are not available.

The Anchorage cost of sulphur-asphalts has been estimated to vary with the cost of plant sulphur. Assuming a plant sulphur cost of $120.00/ton in Anchorage, the sulphur-asphalt mixes of 40/60% and 30/70% by weight are about $21.00 - $29.00/MT (metric ton) in Anchorage.

B. Lightweight Aggregate Costs

Anchorage costs of expanded polystyrene aggregates are not available; but the cost of solid glass aggregates in Anchorage are between $0.30 - $0.50/lb.

C. Mat Costs

1. Aluminum mat costs vary greatly with quantity, shape and surfacings of purchased mats or planking. Costs range anywhere from $8.25 - $20.00/sf, F.O.B. for plain and coated aluminum mats or planking.

2. Plastic and fiberglass mat range from $7.00 - $13.00/sf, F.O.B. California, depending upon the quality of the mats for the cost of fiberglassing the mats desired. The F.O.B. costs of plastic netting are on Table 4.

3. Steel matting costs are not available at this time.

4. Plywood, treated and coated treated and fiberglass coated, costs between $1.80 -$2.50/sf, F.O.B. New York City.

D. Winter Road Costs

Research and experience indicate that the cost of winter road construction and maintenance vary greatly in the Arctic regions. Listed are the approximate costs per mile (1,607 km) to construct and maintain a 30 ft. (10m) wide winter road.

TABLE 4
CIVIL ENGINEERING - PRICE LIST

MATTRESSES

Size	Order Value over $2,400		Order Value up to $2,400	
	Per run. m.	Per Unit	Per run. m.	Per Unit
6m x 1m x 170mm	8.96	53.72	9.44	56.69
6m x 1m x 250mm	9.40	56.31	9.90	59.45
6m x 1m x 330mm	9.92	59.54	10.47	62.85

GABIONS

Type	Order Value over $1,200	Order Value $2,400-12,000	Order Value up to $2,400
2m x 1m x 500mm	26.47	28.00	29.44
2m x 1m x 1m	39.41	40.46	41.47

CIVIL ENGINEERING

Type	Order Value over $12,000		Order Value $2,400-12,000		Order Value up to $2,400	
	per sq. m.	per unit	per sq. m.	per unit	per sq. m.	per unit
CE 111 30m x 2m	1.63	97.46	1.75	104.56	1.87	111.15
CE 121 30m x 2m	2.78	165.78	2.97	177.55	3.14	188.50
CE 131 30m x 2m	2.47	148.13	2.66	158.71	2.83	168.53
CE 151 5m x 1m (Layflat tube)	4.96	24.81	5.35	26.73	5.70	28.52
CE 152 15m x 2m	2.40	71.33	2.56	76.58	2.73	81.47

SAND FENCING/WINDBREAK

Type	Order Value over $12,000		Order Value $2,400-12,000		Order Value up to $2,400	
	per L.m	per unit	per L.m	per unit	per L.m	per unit
30m x 1m	2.44	73.40	2.49	74.79	2.71	81.02
30m x 2m	2.30	137.28	2.40	142.98	2.54	151.59

FENCING

Type	Order Value over $12,000		Order Value $2,400-12,000		Order Value up to $2,400	
	per L.m	per unit	per L.m	per unit	per L.m	per unit
25m x 1.2m	2.64	65.85	2.76	68.72	2.92	73.04
25m x 1.8m	3.91	97.65	4.07	101.94	4.34	108.37

Note: All prices ex works, including delivery and V.A.T.

WINTER ROAD CONSTRUCTION AND MAINTENANCE COSTS
(Does not include clearing costs)

Type of Road	Construction and Maintenance Costs
1. WINTER TRAILS	
a. Temporary	$1,000.00 - $2,000.00
b. Perennial	$1,000.00 - $4,500.00
2. SNOW ROADS	
a. Compacted	$4,500.00 - $6,000.00
b. Processed	$5,000.00 - $8,000.00
c. Ice Cap	$8,500.00 - $13,000.00
d. Artificial	$42,000.00 - $55,000.00
3. ICE ROADS	
a. Solid	$3,000.00 - $28,000.00
b. Aggregate	$28,000.00 - $42,000.00
c. On Natural Ice	$1,500.00 - $4,500.00

E. Quarries

No costs available at this time.

F. Piles

Cost of Arctic pile foundation systems for drilled and slurried in-place piles depends mainly upon the type of piles and the size of the project. The approximate cost for large projects, minimum 2,000 ft.(610 m.) in length, are listed below. Unless stated otherwise, these are approximate costs of the piles in Anchorage, not including installation costs in NPR-A obtained from contractors, architectural and engineering firms, and suppliers in Anchorage.

Untreated wood piles 12 to 14 in. diameter	$25.00 - $45.00/ft.

Installed in Anchorage, 20 ft. long

Steel pipe piles 6 to 9 in. diameter	\$22.00 - \$25.00/ft.
Steel-H piles	\$0.45/lb.
Steel Thermal Piles 6 to 9 in. diameter	\$75.00 - \$100.00/ft.

V. ENVIRONMENTAL CONSIDERATIONS ON THE ALTERNATES

All the alternates except winter roads and pads will be using manmade synthetic materials that are mostly non-biogradable. The chemical, physical and visual potential negative effects of these synthetic materials on the envionment are a possibility. It is important to evaluate these probable effects against the urgent needs and values that will be gained by utilizing these gravel alternates.

Hydrocarbons and sulphur mixtures are the two main alternates that may have potential negative effects after they have been in place for long periods of time. Laboratory analysis and field experiments indicate that to date there in an insignificant amount of chemical effect on the environment by their use. The Economic analysis of the construction process should that they will be used mostly on permanent rather than temporary structures. The environmentally negative effects due to in-place decaying of these materials because of lack of maintenance will probably be negligible.

The potential for causing physically begative environmental effects from these alternates may be limited only to quarrying operations. These potential negative effects are considered long-term and irreversible. Careful evaluation of the importance.

The probable visual negative effects on the environment are an inescapable fact when any industry comes into a naturally wild area similar to NPR-A. All the alternates mentioned in this paper have a potentially negative visual effect. Alternate materials used on temporary embankments may be the most esthetically unpleaseing. Before permits are issued, these temporary embankments must be scrutinized carefully. Stipulations that nullify visually negative effects which may be imposed on the natural setting after the use of temporary structures must be vigorously enforced.

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